ARMATURE WINDING

A Practical Book on the Construction, Winding and Repairing of Alternating-Current and Direct-Current Motors and Generators, with Practical Connection Diagrams

★

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★

ILLUSTRATED

AMERICAN TECHNICAL SOCIETY

WINDING STATOR OF 40,000 KW. 257 R.P.M., 60-CYCLE, 13,800 VOLTS ALTERNATING-CURRENT GENERATOR TO BE USED AT BOULDER DAM

Courtesy of Allis-Chalmers Mfg. Co.

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INTRODUCTION

WITH the discovery of electromagnetism as a source of energy, electrical science progressed from an interesting phenomenon to the beginning of modern industrial development. Picture the world today without the dynamo, the electric light, electric cars, the telephone, the wireless telegraph, or the radio. In a few short years this progress has been made, and with the present knowledge of electrical science, what may not be done during the lifetime of present scholars and experimenters?

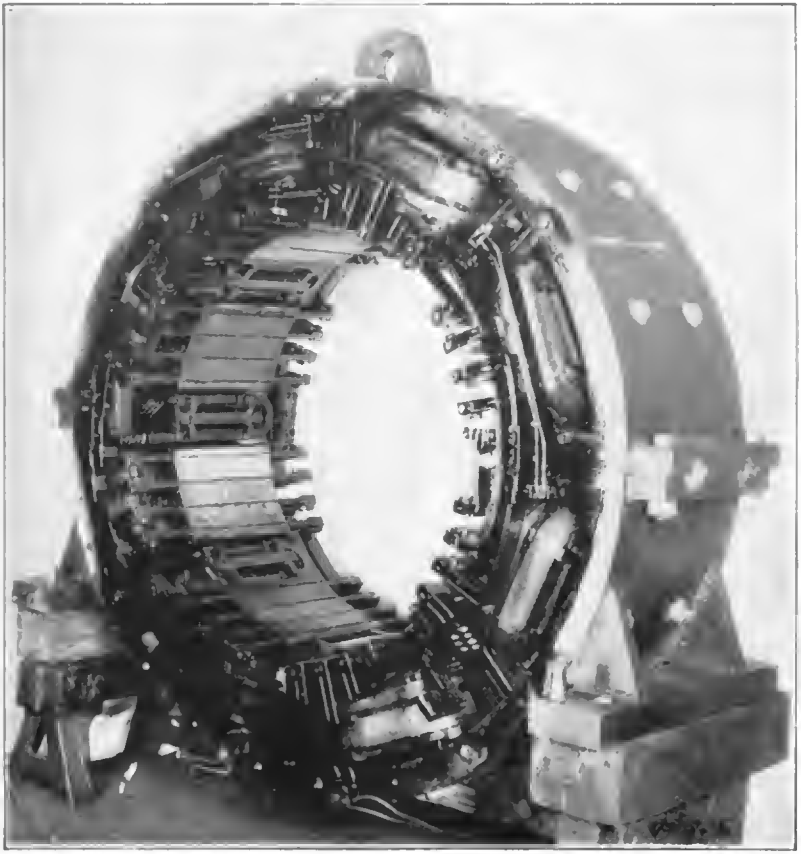
As the armature, with its windings of insulated wire, is the heart of the whole system of electrical energy, this phase should receive special study. And it is with the purpose of showing the practical and theoretical considerations due the subject of armature winding that this volume has been prepared.

For many years only an inkling of the principles of electrical energy was known. From time to time discoveries, the result of experiment rather than of calculation, led inventors nearer and nearer to one hundred per cent in electrical efficiency. Long observations of electrical effects led to more or less empirical formulas, which have been corrected from time to time as additional observations corrected original impressions. Advances in mechanical and chemical processes have aided in making electricity the willing servant of mankind, until today the weight of the water in the mountain stream traveling from the far-off hills to the distant sea becomes, through the armature of the dynamo, the energy which lights our cities, turns the wheels of industry, and carries our messages around the world. The development of the armature has thus had much to do with bringing about this happy condition in our economic existence.

In preparing this volume the authors have drawn heavily upon their wide experience in the theoretical and practical design of electrical apparatus. Practically all of the line drawings have been

drawn especially for this work, while the photographic reproductions represent the best practice of modern shops.

Such advances have been made since present workmen were in school that it has become necessary for many to supplement school knowledge with information brought down to date. This volume is therefore particularly adapted for purposes of home study and self-instruction. The treatment of each subject will appeal not only to the technically-trained expert but also to the beginner and to the shop-taught practical man who wishes to keep abreast of modern progress. Without sacrificing any of the essential requirements of thorough practical instruction, the authors have avoided many of the heavy technical terms and formulas of higher mathematics, producing a book in clear and simple language on this important branch of electrical work.



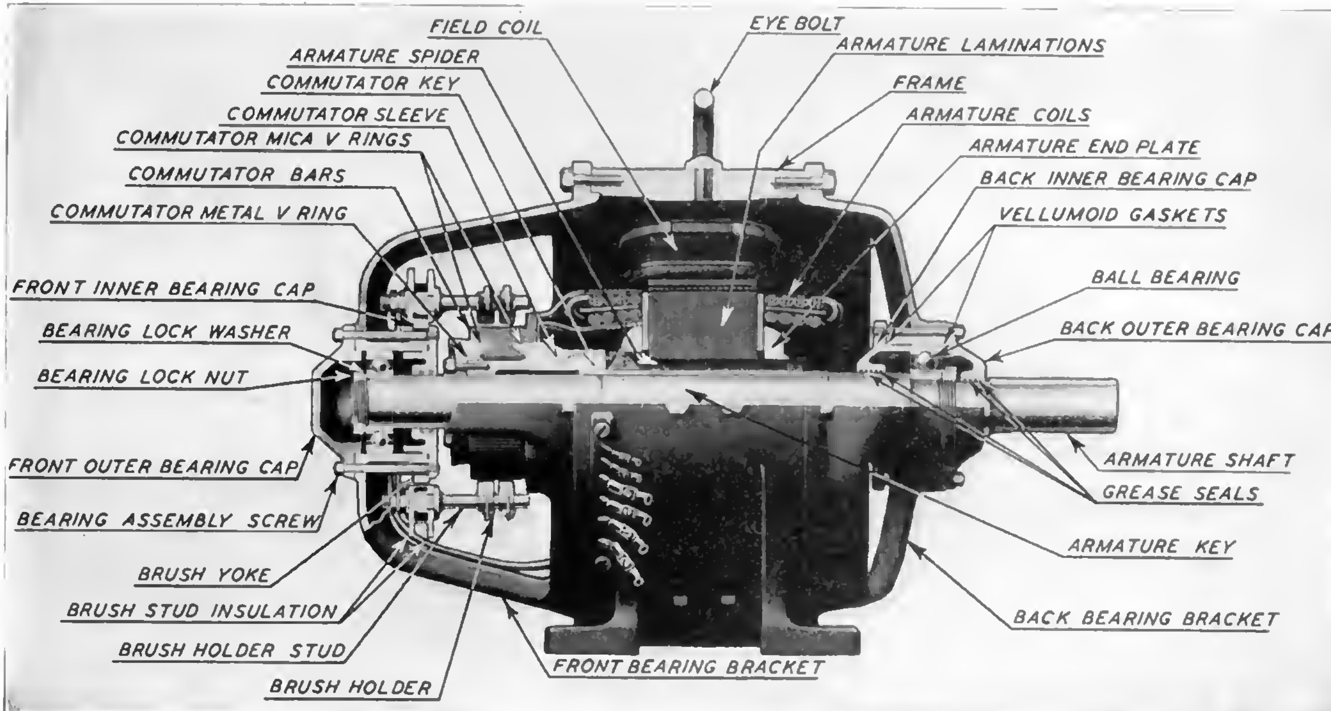
CONSTRUCTING A DIRECT-CURRENT GENERATOR

The compensating field winding is placed in slots cut in the face of the main shunt and series field pole pieces.

Courtesy of Westinghouse Electric and Manufacturing Co.

CONTENTS

Page



A BALL-BEARING FULLY-ENCLOSED FAN-COOLED DIRECT-CURRENT MOTOR
Courtesy of Reliance Electric and Engineering Company

TYPES OF ALTERNATING-CURRENT GENERATORS

The only difference between a simple direct-current generator and a simple alternating-current generator is that the direct-current generator has a commutator and the alternating-current generator has slip rings. From this slight difference in construction comes the difference in the voltage and kind of current obtained from the two units.

FREQUENCY OF ALTERNATING-CURRENT

Frequency of an alternating current is the number of cycles the current passes through in one second. A complete turn of a loop of wire will make one complete voltage cycle as shown in Fig. 1. One-

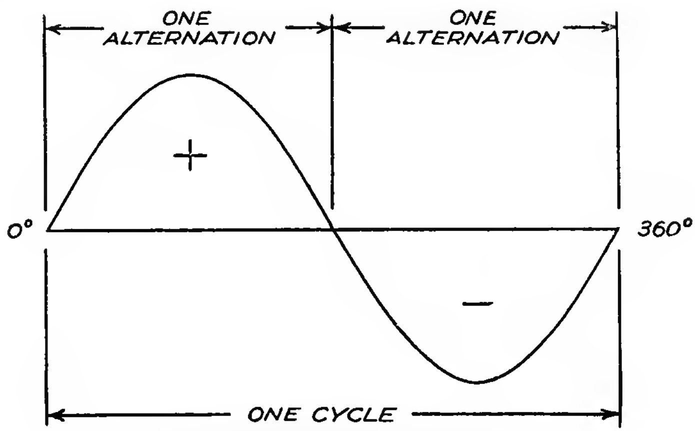


Fig. 1. Curve of Voltage Obtained from Revolving a Loop of Wire by a Pair of Poles

half the rotation of the loop will produce a voltage in a positive direction which causes current to flow out on the outside slip ring, and the next half turn completing the revolution would cause the outside ring to be negative. This shows that the current flows equally in both directions during a cycle. A reversal of current is called an alternation. Two alternations make one complete cycle.

Speed and Number of Poles. If this coil had rotated by two pairs of poles, the effect would have been just the same, as a coil making two complete turns with one pair of poles. Each time a coil or group of coils together pass a pair of poles a cycle is made. Obviously the speed and the number of poles will affect the frequency. Mathematically, frequency equals the poles times the revolutions per second divided by two and is often expressed as follows:

$$\text{Frequency} = \frac{\text{r.p.m.} \times \text{p}}{60 \times 2}$$

If the poles were rotated and the field coils remained stationary, the frequency would be exactly the same as it is with the revolving

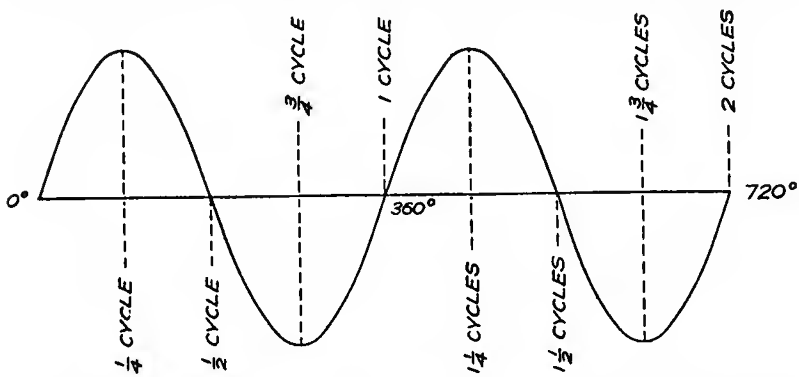


Fig. 2. Curve Showing Variation of Voltage When Loop Makes Two Complete Turns or Two Pairs of Poles Are Used

loop. A pair of poles passing a coil produce two alternations or one cycle, and the coil passes through 360 electrical degrees. If this had been a 4-pole machine, two complete cycles, Fig. 2, would have occurred on the coil or 720 electrical degrees. Each pair of poles adds a cycle to the loop for each revolution that either the coil or the poles make.

Some small alternating-current generators use the revolving armature like a direct-current generator, but for two very important reasons the larger machines without exception use the revolving field in which the poles rotate. One important reason revolving fields are used is due to the fact that insulation stands up better if it is stationary, and the other is no sliding contacts for the large

currents are necessary with revolving fields. Moving parts are also lighter with the latter arrangement. Fig. 3 shows the various positions of the revolving loop with corresponding voltage produced in Fig. 2 for each quarter cycle. No voltage is produced at the first and third positions of the coil as the conductors are not cutting the flux in these positions as shown by Fig. 2. As the coil leaves the starting position, as shown in Fig. 3, the voltage gradually increases

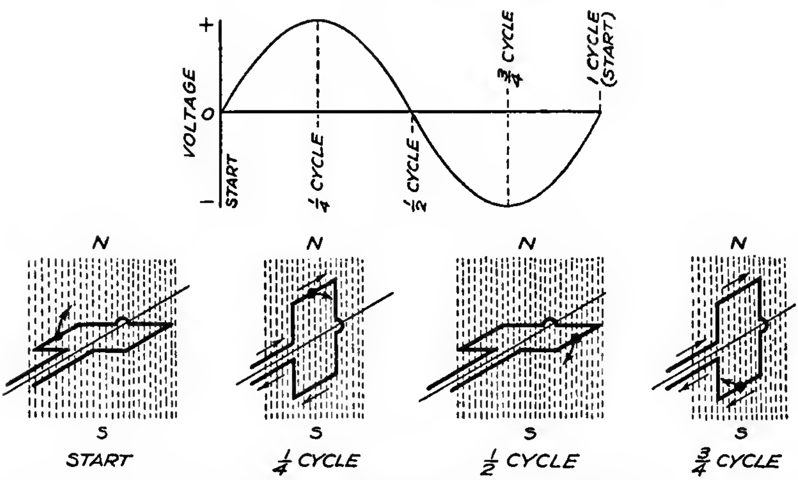


Fig. 3. Loop Positions and Instantaneous Voltages Shown as a Single Loop of Wire Is Revolved in a Magnetic Field

and the second picture shows the voltage at the highest point when the quarter cycle position is reached.

SINE CURVE

The sine curve shown in Fig. 1 is the standard of reference for all discussion on alternating current. This curve can be plotted graphically by using a sine table and the corresponding angles. The sine itself is simply the ratio of two sides of a right-angled triangle, being the altitude divided by the hypotenuse. The cosine referred to in power factor discussions is the ratio of the base to the hypotenuse. Each angle always has the same sine value, likewise a cosine value which is always the same number for any particular angle. A curve plotted from the sine values would always have a maximum value of one.

The sine curve, shown in Fig. 4, can be developed mechanically

from a circle as follows: Starting with a point A at position O make a circle about a center C. Draw a horizontal line to the right of the circle from O to B and divide it into sixteen equal lengths. (For more accurate work, more divisions should be used.) This line represents the time it takes point A to go around the circle and is measured in degrees 0 to 360. Divide the circumference of the circle into the same number of divisions as there are in the horizontal line. A vertical line from each one of these division points on the cir-

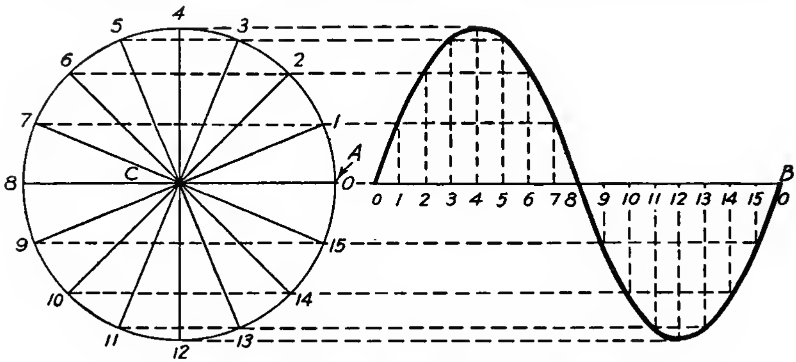


Fig. 4. Development of a Sine Curve from a Circle

cumference to the horizontal line through C represents the value of voltage generated at this particular instant by the coil in passing through the pole flux. These lengths laid off vertically on the horizontal line will give points through which the sine curve can be drawn, as shown in Fig. 4.

The voltage curves for generators do not conform to the sine wave usually pictured, but take shapes similar to those shown in Fig. 5. These shapes give better operating results and are used with practically all commercial machines. The shape of this voltage wave can be changed to any desired form by changing the contour of the pole face. In this figure the pole face is flat and the air gap uniform, which produces the wave form shown. If the pole face was changed slightly so as to weaken the flux density at the front and rear sides of the pole, the wave form would be more peaked and would look more like the sine wave. The wave form shown in Fig. 5 is made by a single coil in the armature slot. Commercial generators ordinarily have more than one coil per slot so the wave form is not quite so flat topped but is more like the sine curve.

PHASE

The term phase, as used in electrical work and in literature, has two separate and distinct meanings. Unless these are clearly and definitely understood a great deal of confusion may result. One

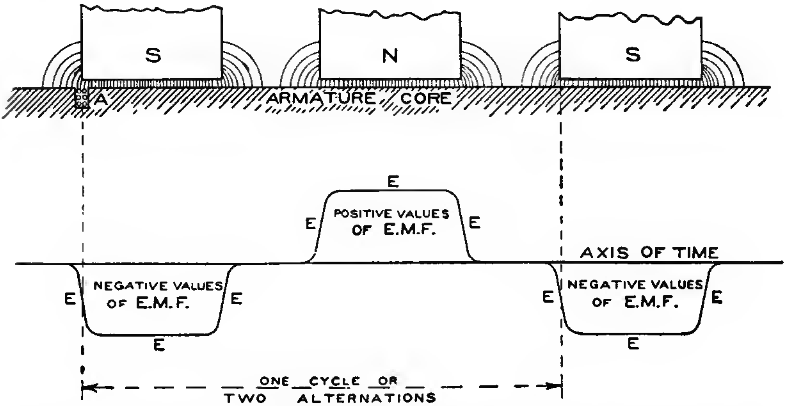


Fig. 5. Development of Magnetic Fields and Voltage Curve Obtained from Them

meaning of the term phase has to do with circuits. Single-phase, two-phase, three-phase, and six-phase circuits are frequently mentioned in discussing alternating-current circuits.

A single-phase circuit may be defined as one which has voltage

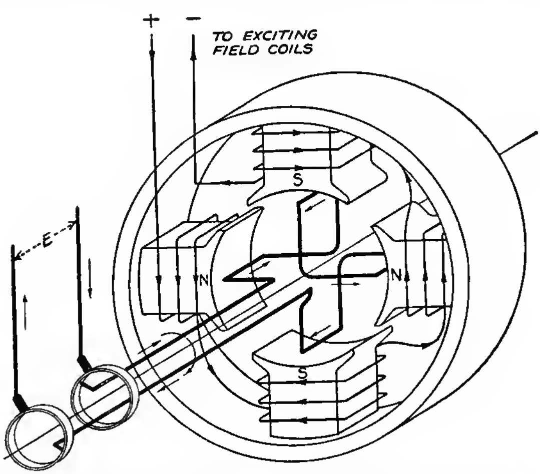


Fig. 6. A Single-Phase Alternator with a 4-Pole Revolving Armature. Phases are determined by windings and not by the number of poles

impressed upon it from only one alternating-current source. A single wire or coil revolving in a magnetic field will produce a single-phase circuit. The revolving coil shown in Fig. 3 would be a single-phase generator. The number of turns or the number of loops would

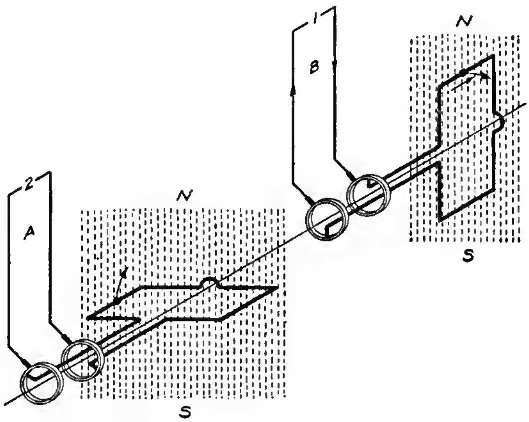


Fig. 7. Elementary Two-Phase Generator

not change the phases which are also independent of the number of poles as shown in Fig. 6. Although this machine has four poles and two loops, it is only a single-phase generator, as there is only one voltage wave acting on any circuit connected to the slip rings.

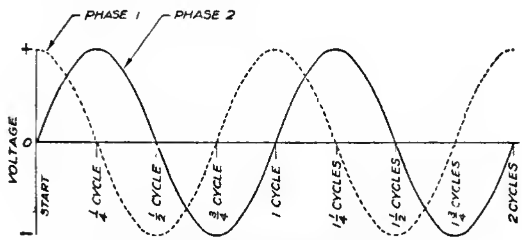


Fig. 8. Voltage Waves Generated by Two-Phase Generator—A Two-Phase Voltage Curve

A two-phase circuit in reality is two separate single-phase circuits, each with its own voltage wave impressed upon it. These two equal voltage waves are 90 degrees apart and always maintain this relationship. Fig. 7 shows a simple two-phase generator with the two separate windings 90 degrees apart rotating on the same shaft. This also shows the required two sets of slip rings and the

independent circuits 1 and 2 having absolutely no electrical connection with each other. The voltage waves produced by this generator are shown in Fig. 8. These are 90 degrees apart at the start and always maintain this relationship because the coils in the

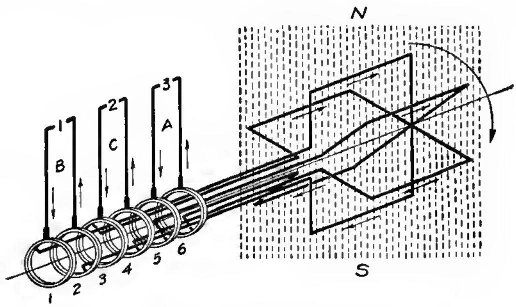


Fig. 9. Elementary Three-Phase Generator with All Six Leads Brought Out

generator generating the electromotive forces are set at the same angular displacement and cannot shift position.

A three-phase circuit is one in which three separate equal voltage waves are impressed 120 degrees apart on three circuit voltages. These may function on six wires but three wires ordinarily make a three-phase circuit. Fig. 9 illustrates a three-phase

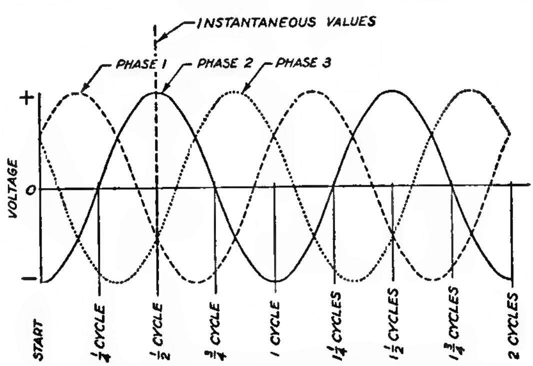


Fig. 10. Voltage Waves Generated by a Three-Phase Generator—A Three-Phase Voltage Curve

generator with all leads brought out to six-slip rings making a six-wire three-phase circuit. This is in reality three separate single-phase machines operating in the same magnetic field which makes all voltages equal. These circuits are often referred to as phases *A*, *B*, and *C* especially in line work and armature winding in order to

keep connections in correct order. The voltage waves shown in Fig. 10 show the relationship and position of the various voltages in a three-phase circuit. Because of the 120-degree spacing of the coils on this generator, all three voltage curves remain this same distance apart as shown in Fig. 10. A three-phase circuit has this particular characteristic. The instantaneous value of the voltage on one phase will be exactly equal to the algebraic sum of the voltages on the other two phases. Take the point where phases 1 and 3 cross below the line.

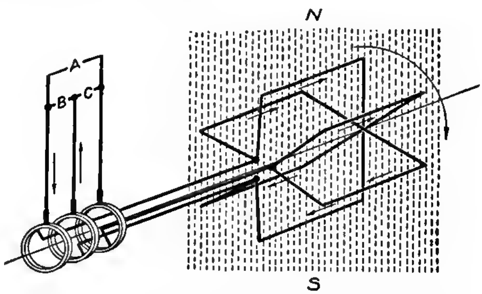


Fig. 11. Three-Phase Generator with Usual Internal Connections and Three Leads Brought Out

Measure this distance, and it will be found to be just half the distance to phase 2 above the line. This means that the sum of the two negative voltages on phases 1 and 3 will just equal the positive voltage on phase 2. All other points will give identical results at any position checked.

Because of this voltage condition on a three-phase circuit, the coils can be connected together inside the generator making only three slip rings necessary as shown in Fig. 11. This arrangement of coils enables each line to be a part of two phases as shown by *A*, *B*, and *C*, and each ring serves two coils in the generator which is standard in winding practice.

The other meaning of the term phase has to do with current and voltage relations within the circuit itself. When a load having ohmic resistance only is connected to a source of alternating-current voltage, the current wave will follow the voltage wave instantly, which means that current will be zero when the voltage is zero and reach a maximum value when the potential is at the peak, as shown by the curves in Fig. 12. The current and voltage are said to be *in phase* when this relationship exists.

A very few alternating-current electrical circuits have only ohmic resistance opposing the flow of current in them. Inductance or capacity, and in some cases both, are present along with the ohmic resistance to limit the flow. Inductive reactance is caused by the magnetic effects set up when alternating current flows in

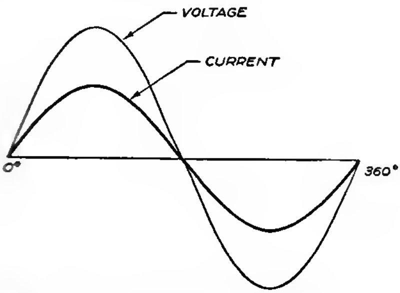


Fig. 12. Voltage and Current in Phase in a Single-Phase Circuit

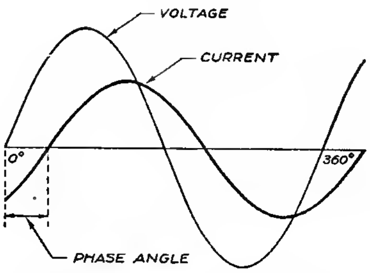


Fig. 13. Voltage and Current Out of Phase in a Single-Phase Circuit

coils with an iron core such as are found in transformers, motors, and choke coils. This inductive effect from the alternating magnetic field acts like counter electromotive force on the flow of current and delays the time when it reaches a maximum value. Whenever this condition exists in a circuit, the current is said to be lagging behind the voltage and is *out of phase* as shown by Fig. 13. In this case the voltage and the current do not pass through zero or reach a maximum value at the same time. The current passes

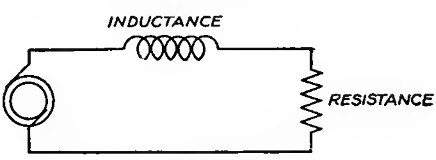


Fig. 14. Choke Coil and Resistance in Single-Phase Circuit Producing Effect Shown in Fig. 13

through zero at a later time and reaches a maximum later than the voltage maximum. The angle between them, measured along the horizontal line between the points where the curves cross it, is called the *phase angle* between the current and the voltage. The cosine of this angle is the *power factor* for the circuit. Fig. 14 shows a choke coil in series with resistance connected to a source of alternating current producing the effect shown in Fig. 13. All three

types of opposition to current flow, whether it is ohmic, inductive, or capacity, are measured in ohms. These combine differently in an alternating-current circuit than the ohms of a direct-current circuit. Inductive ohms and capacity ohms act at right angles to the resistance in the circuit when both are present. Fig. 15 shows three conditions which may exist in an alternating-current circuit. In Fig. 15 at *A* is illustrated the relationship existing in a circuit of the type shown in Fig. 14. The three sides of the triangle are made from the following: the base *R* is the ohmic resistance, the

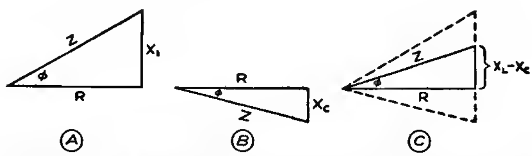


Fig. 15. Triangular Relations of *A*—Resistance and Inductance; *B*—Resistance and Capacity; and *C*—Resistance, Inductance, and Capacity. These control the current flow in an alternating-current circuit

altitude X_L is the ohms reactance due to the magnetic effect, and the hypotenuse *Z* is the *impedance* or actual resistance to the flow of current in this circuit. In all mathematical calculations involving Ohm's law in alternating-current circuits, the current is obtained by dividing the volts applied to the circuit by the impedance. Impedance in each case must be found from the triangle developed in Fig. 15 at *A, B,* or *C* as the circuit conditions demand. In Fig. 15 *B* shows how capacity and resistance combine to control the current flow when capacity is present. *C* illustrates the combined effects on the impedance of a circuit having resistance, inductance, and reactance. The magnetic and capacity effects are 180 degrees apart and neutralize each other leaving only the difference to combine with resistance to form impedance. Because of this neutralizing action between capacity and induction, it is possible to change the power factor of any alternating-current circuit. On account of these magnetic effects, capacity in the form of static condensers or synchronous condensers is used to correct poor power factor.

The phase angle ϕ between the impedance and the resistance in Fig. 15 is the same as the angle between the current and the voltage in Fig. 13, because the current lag is caused by the same magnetic effect which determines the size of the angle ϕ in the triangle.

POWER FACTOR

Power factor is the ratio of true power to apparent power. It is the wattmeter reading divided by the apparent power. The apparent power is the product of the ammeter reading multiplied by the voltmeter reading. This division gives the power factor, because the triangle of real watts and apparent watts is similar to the impedance triangle shown in Fig. 15.

The power triangle shown in Fig. 16 is made from the volts and amperes which are the apparent watts in the circuit and the wattmeter reading. The magnetizing power may be measured with a

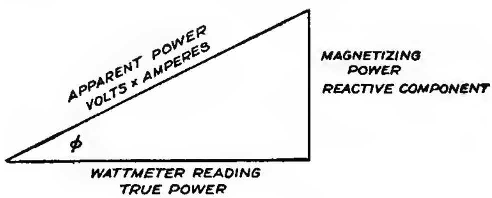


Fig. 16. Power Triangle of an Alternating-Current Circuit

reactive meter or may be calculated from the two previous sets of readings in the same way that the sides of any right-angled triangle may be found. Or the angle ϕ may be found from a table of cosines, as the wattmeter reading divided by the apparent watts gives the cosine ϕ. A protractor is used to lay off the angle and the magnetizing power is determined. This is a graphic method often used as a check on mathematical calculations. The reason these triangles are similar is due to the fact that inductance in an alternating-current circuit divides the current and voltage into two components, one acting on the resistance to produce useful work, and the other acting on the reactance to overcome the magnetic conditions in the circuit shown in Fig. 14.

TYPES OF WINDINGS

An alternating-current generator is a machine used to produce alternating current. It is made with three different types of windings to produce single-phase, two-phase, or three-phase current, depending upon what application is to be made of the power derived from the machine.

Direct current is almost always employed for exciting the

fields of alternating-current generators or synchronous motors. These direct-current exciters may be separately driven or mounted on same shaft as the alternator. Separately driven exciters are preferable, because they give more stable voltage conditions than the direct-connected machines. Exciters mounted on the same shaft with the main generator cause double the voltage variation with a change in speed as a separately driven unit, because an increase in speed will not only raise the alternator voltage but will increase the exciter current through the field. Thus a one per cent rise in speed

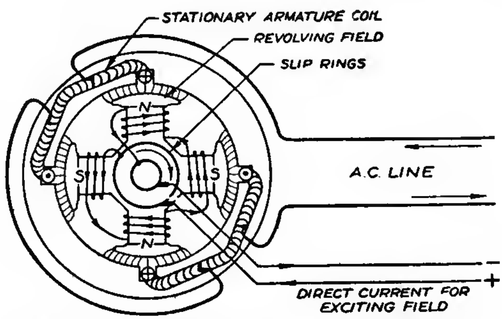


Fig. 17. Single-Phase 4-Pole Revolving Field Type of an Alternating-Current Generator with Only One Group of Coils

will not only raise the alternator voltage one per cent but will at the same time increase the field one per cent which would make two per cent change on the main line voltage. Separately driven units are more flexible in a large plant as one exciter may be made to supply the field for one or more generators, or exciters may be operated in parallel with other direct-current machines doing the same service.

Single-Phase Alternator. As explained in the earlier pages of this lesson, a single-phase alternator is made with but a single winding in the part connected to the line and supplying power. The field may be made with any number of pairs of poles. Fig. 17 illustrates a single-phase, 4-pole, revolving field type of alternating-current generator. The moving parts of alternating-current machinery are nearly always referred to as the *rotor* while the stationary part is called the *stator*. The slip rings supplying the field are connected to some source of direct current. There is but a single set of coils on the stator and hence only one source of voltage which

makes this machine a single-phase alternator. In many cases a three-phase generator is so connected that two-thirds of the coils are used for a single-phase machine. This arrangement will permit the machine to deliver 65 per cent of its three-phase capacity.

Any machine operating as a single-phase alternator should be very carefully laminated throughout its magnetic circuit to reduce iron losses, and the pole shoes should have a heavy squirrel cage

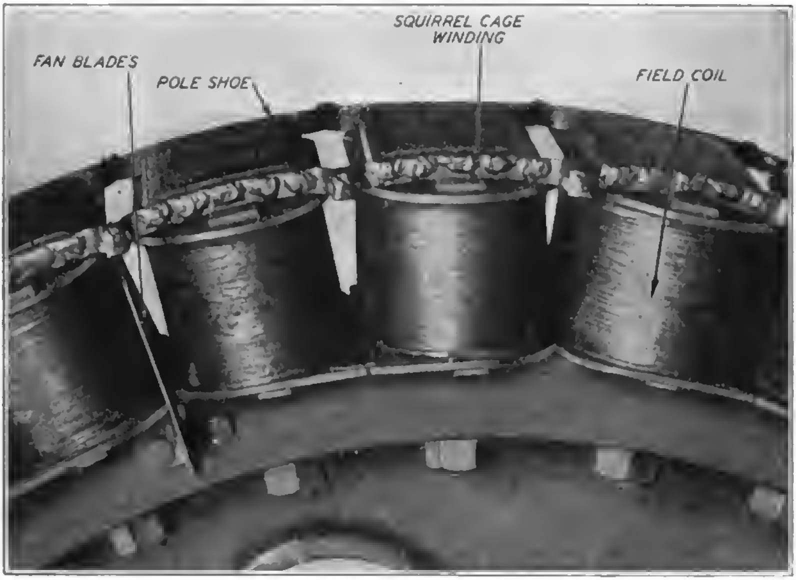


Fig. 18. A Partial Rotor Assembly Showing Method of Fastening Field Coils and Poles to Rotor
Courtesy of Electric Machinery and Manufacturing Company

winding provided to damp out the pulsating effects of the armature reaction. Fig. 18 shows a sectional view of a rotor with the squirrel cage winding in the pole shoe. These poles are assembled from their laminated punchings riveted together under hydraulic pressure. The squirrel cage or damper winding is welded on each side to insure a low resistance circuit completely around the rotor as this greatly increases the effectiveness of this type of winding.

For the same kilovolt amperes output, single-phase generators are fully 65 per cent heavier than a polyphase generator of the same power factor, speed, and voltage. This makes them not only more expensive to build, but increases all other investment costs.

Single-phase generators find application in electrochemical processes and some railway systems use single-phase power. Welding transformers and electrical furnaces use single-phase generators, so power sometimes has to be supplied for these particular applications where access to a power company line is not convenient. They also find some service in testing and experimental work.

Single-Phase Two-Wire System. The single-phase generator connected to a line gives the two-wire system as shown in Fig. 17. As alternator voltages are usually higher than secondary distribution voltages, a transformer is required between the generator and the load. The voltage used on a two-wire system is usually 110 volts and alternators generate 220, 440, 1300, 2300, 4000, 6600,

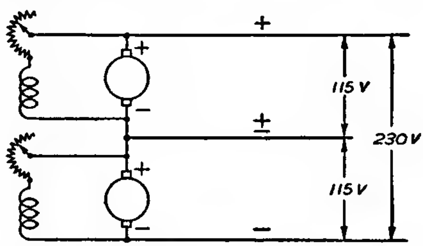


Fig. 19. Edison Direct-Current Three-Wire System

13,200 and a few 33,000 volts. The transformer ratio to produce 110 volts on the line will depend upon the voltage at the source.

Single-Phase Three-Wire System. The single-phase three-wire system has the same advantages for alternating-current systems as obtained with the three-wire direct-current systems discussed in Lesson 28. It is usually obtained on an alternating-current line by using a center tap on the secondary winding of the transformer. This method of obtaining the three-wire system has the added advantage of being able to handle any amount of unbalance there might be, whereas, the balancer systems are definitely limited in ability to handle over a certain per cent of unequal load.

Edison System. The Edison three-wire system for direct current was originally developed and used by Thomas A. Edison. He connected two 2-wire generators in series and connected the middle wire to the center point of the two machines as shown in Fig. 19. This arrangement provided two voltages, one for light and the other for power and, at the same time, cut down transmission losses. Any

amount of unbalance in the load is taken care of without additional equipment. However, too much unbalance causes an excessive voltage on the side of the line with the smaller load. A similar system is used for alternating current from taps on transformer windings.

Two=Phase Alternator. The two-phase generator is exactly like the single-phase alternator except that it has two separate windings on the stator. These windings make two entirely separate electrical circuits which have no connection with each other. The second winding, phase two, is spaced exactly between the coils on the

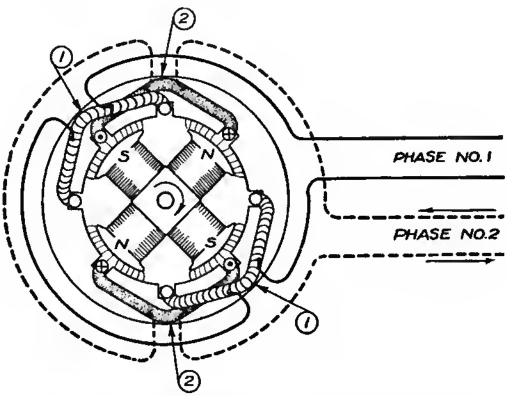


Fig. 20. Two-Phase 4-Pole Revolving Field Type of an Alternating-Current Generator with Only Two Groups of Coils

generator in Fig. 17. With the poles in the position shown in this figure, the voltage on *phase 1* would be at a maximum as illustrated by the voltage at the start in Fig. 8. At this instant the voltage on *phase 2* is zero because the pole flux is not cutting the coils on this phase at this instant. The position of the poles one-eighth of a revolution later, Fig. 20, indicates that the voltage on *phase 2* is maximum and *phase 1* has decreased to zero. This condition is shown in Fig. 8 at point marked ¼ cycle. Because these curves are 90 electrical degrees apart and always remain in this relative position, the two-phase system is sometimes called the *quarter-phase* system, this being just one-fourth of a cycle which is 360 degrees.

Four=Wire System. An inspection of Fig. 20 shows four wires required to complete each of the circuits for the two phases. Whether these circuits are used for supplying power for lights or motors, they

are complete and independent throughout with the voltages remaining on the quarter-phase angle with reference to each other.

Three=Wire Two=Phase System. The two-phase four-wire system may be converted to a three-wire system by making one line wire common to both phases or circuits. In order for this wire to handle the currents in both phases, the area of copper must be approximately 41 per cent larger than either of the other two. The current caused by the common wire is exactly the square root of two which is 1.41 times the current in either outside line.

The principal reasons for developing polyphase systems was

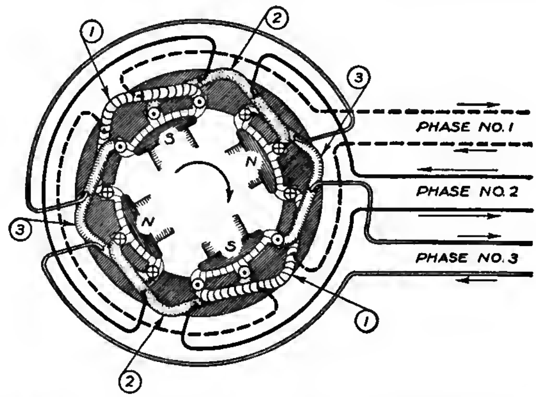


Fig. 21. Three-Phase 4-Pole Revolving Field Type of an Alternating-Current Generator with Only Three Groups of Coils

for the use of electric motors and savings in transmission costs. The early single-phase motor would run, but no means was known for developing torque for starting. Primarily, to meet this situation, two-phase systems were put into use. As soon as the three-phase circuit was discovered, its numerous advantages over a two-phase circuit made it so popular that very nearly all power systems changed over and the two-phase circuit has almost become history.

Three=Phase Alternator. The three-phase alternator is made by adding another phase to the two-phase machine. The addition of another set of coils makes a considerable difference in the voltage relations as will be seen from an inspection of the voltage curves shown in Fig. 10. The two-phase voltages were 90 degrees apart while these curves are separated by 120 degrees, which relationship is always maintained due to mechanical arrangement of stator coils.

This three-phase relationship is obtained by winding three sets of coils on the stator. They are practically always spaced 60 degrees apart, and one group is reversed so that the electromotive forces will be separated by 120 degrees. In Fig. 21 is shown a three-phase stator with the necessary three groups of coils. These are spaced exactly 60 degrees apart and all six ends brought out for each circuit. The pole position with reference to the different phases will give instantaneous voltages shown at the start of Fig. 10. The instantaneous voltage on phase two is at a maximum but is negative and is just starting toward zero, while the instantaneous voltages on phases one and three are both positive, but one is on the increase and three is already decreasing. This condition is explained from an inspection of Fig. 21. The two south poles are exactly under the coils in phase two producing a maximum negative voltage as shown by Fig. 10. The two north poles are partially over both phases one and three. As the rotor is revolving in a clockwise direction, the north poles are approaching phase one thus increasing the voltage positively, as shown in Fig. 10, and leaving phase three which causes a decrease in voltage as shown on the curve for phase three.

The leads to phase one have been reversed, which changes the voltage relations in the three phases from 60 degrees to 120 degrees. Windings for two- and three-phase stators are never wound, as shown in Figs. 20 and 21, this plan being used for simplicity in showing the phase relations. Factory windings for these machines would place sides of different coils in the same slot where the currents in the two sides would be in the same direction, as this arrangement gives more effective use of the iron. The diagrams become involved and difficult for the beginner to follow and understand the volutions in the various phases.

Six-Wire System. If all leads of the three-phase groups are brought out as shown in Fig. 21, six lines will be required and the system would be known as the six-wire system but would be only a three-phase system. This arrangement should not be confused with the conditions made by the windings of the ordinary three-phase alternator where six coil groups are used for each 360 magnetic degrees or pairs of poles. This coil arrangement would cause six different electromotive forces which would be 60 degrees apart or one-sixth of a cycle and would be known as a six-phase system.

If, however, the coil leads are connected either star or delta and three leads connected to the load, the resulting currents will differ in phase by 120 degrees. Thus an alternator may be either a three-phase or a six-phase machine depending upon the connections to the load.

Star-Connected-Four-Wire System. Figure 22 shows the coil groups in each phase connected together and the groups arranged at the 120-degree phase angle existing between each phase in the alternator shown in Fig. 21. Because of the fact that the instanta-

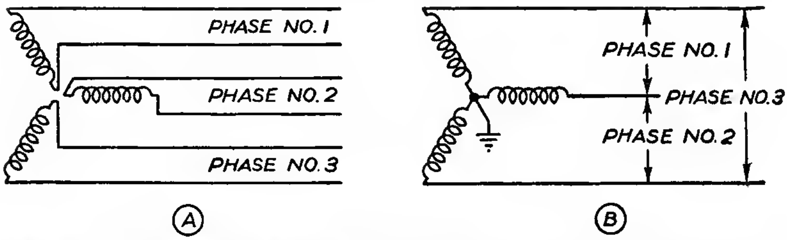


Fig. 22. *A*—Schematic Diagram of a Three-Phase Generator and a Six-Wire System; *B*—Three-Phase Generator Windings Y-Connected, Forming a Three-Wire System

neous value of voltage or current as shown by the curves in Fig. 10 is zero, each wire will act as a return for the other two. This makes possible the connection of the coil ends at the center of Fig. 22 at *A* which eliminates one wire from each phase and results in the wiring connection shown at *B*. A ground wire is frequently connected to the center tap and carried with the phase wires from the alternator through the whole distribution system. When this is done, the circuit is called the four-wire three-phase system.

The star connections of the coils, shown in Fig. 22 at *B*, places two groups of alternator coils in series for a one-line phase at the angle of 120 degrees. This results in a higher voltage on the line by the square root of 3 or 1.73 over the electromotive force obtained from one group of alternator coils with the connections as shown at *A*. Thus the alternator would have a higher voltage output but a more limited current output with this connection, no gain in power being accomplished.

The four-wire system of distribution permits an increased load on a three-wire line of nearly 75 per cent. Higher voltage transformers and motors may be used with resultant savings. Where this system has been tried, it has proved very satisfactory and ap-

parently no more hazardous with a good ground network than other grounded systems. A power company having a three-wire ungrounded system can, by increasing the generating capacity, changing the transformer connections, and using the fourth grounded wire, increase the total load on the lines practically 75 per cent.

Delta-Connected-Three-Wire System. Figure 23 shows the three coil groups for each phase in such a way that when they are joined

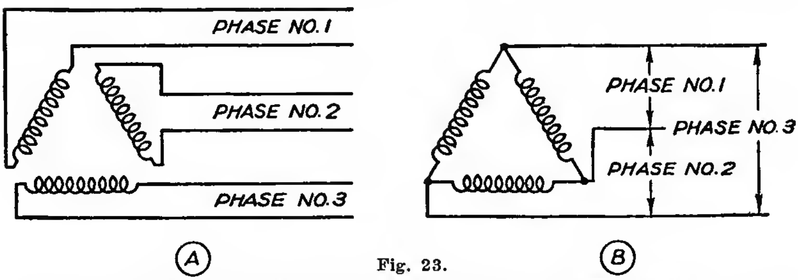


Fig. 23.

Three-Phase Delta Connection—Six Wires and Three Wires
A—Another Method of Showing a Three-Phase Generator Windings and a Six-Wire System; *B*—Three-Phase Generator Windings Delta-Connected, Forming a Three-Wire System

together they form a triangle or circular arrangement. Since there are 360 degrees in one cycle, this makes the three lines 120 degrees apart with reference to their phase relations. The delta connection gives the same voltage on each phase as the generator coil groups produce, but it increases the current delivered to the line by the square root of 3 or 1.73 due to the phase relationship.

The delta system is used extensively for transmission and distribution work. This connection is frequently used in winding induction motors as well as alternators. The power measured in kilovolt amperes is the same in an alternating-current generator regardless of the coil connection. With the star connection the voltage is higher by the square root of 3 and with the delta connection the current capacity is increased by the square root of 3 while the voltage remains at the single-phase value. Expressed mathematically, the power of the three phases of an alternator is: $P = EI \times \sqrt{3}$, where P is the power, E the voltage, and I the current for each phase as shown at *A*, Fig. 22. In the three-phase star-connected arrangement shown at *B*, Fig. 22, this becomes $P =$ (sq. root of 3) $\times E \times I$, where P is the three-phase power and E and I are the voltage and current the same as in the single-phase circuits. Power for the delta

connection is given by the formula $P = E \times$ (sq. root of 3) $\times I$ and applies to *B*, Fig. 23. Thus power is the same from an alternator regardless of which connection is used, but the star or Y connection delivers higher voltage to the transmission while the delta connection raises the amount of current which can be supplied, the voltage remaining the same as the single-phase potential.

CONSTRUCTION OF ALTERNATORS

Rating. The heating caused by the current in an alternator will determine its output. At normal voltage and normal current, a generator should not heat to a greater temperature than 40° C and should deliver its definite kilowatt rating at unity or 100 per cent power factor. Since the connected load determines the power factor at which the alternator must operate, its rating is usually given in kilovolt amperes, which is less than a kilowatt unless the power factor is unity. The rating if given in kilowatts is easily changed to kilovolt amperes by dividing the kilowatts by the power factor. A machine with a rating of 100 kilowatts would become a 125 kilovolt ampere rating at 80 per cent power factor. Ratings are frequently given in kilovolt amperes at 80 per cent power factor on the name plate of the machine.

Mechanical. Alternators may be made with revolving armature, where the generating coils rotate, or with rotating fields with the generating coils stationary. Practically all commercial machines use the latter construction while a few small alternators are built with moving coils. These require all the power current to be picked up with brushes on slip rings and more difficulty is experienced insulating the higher voltages found on the generating coils. Lighter moving parts cut down vibration with revolving field types and make machines with less weight per unit of output, all of which accounts for the preference shown for revolving field alternators.

The rotor or armature of the stationary field type of alternating-current generator is made by assembling laminations punched from special electric sheet steel. These punchings are varnished with special core varnish and assembled under pressure on a cast or steel spider to which they are securely fastened. Spaces are left when assembling to permit free circulation of cooling air. The coils on lower voltage armatures are wound with double-cotton or single-

cotton enamel magnet wire. These are then taped with cotton and oil linen tape, treated with waterproof and oilproof baking varnish, and dried in an oven at controlled temperatures. Slot insulation is made from a combination of insulating paper and varnished cloth.

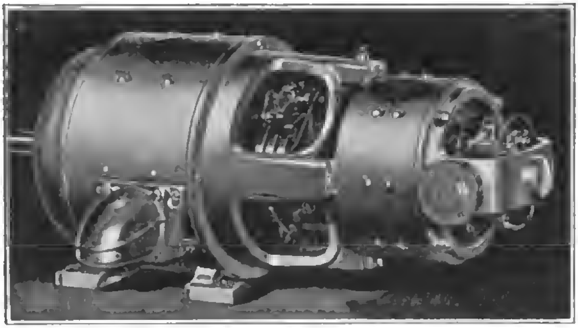


Fig. 24. An Alternating-Current Generator with a Direct-Connected Exciter
Courtesy of Imperial Electric Company

The coils are held in the slots with wood or fiber wedges which fit into dovetails in the teeth of the rotor.

The collector rings for revolving coil armatures are made of special bronze in order to improve wearing qualities and have low contact drop at the brushes. These rings must be thoroughly insulated from the rotor spider and yet be securely fastened to it. Fig. 24 shows an alternating-current unit made in capacities from

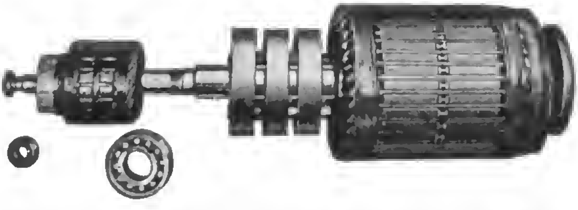


Fig. 25. Alternating-Current Winding on Rotor of Alternator (Right) and Direct-Current Armature of Exciter (Left) Mounted on Same Shaft
Courtesy of Troy Engine and Machine Company

1 to 150 kilovolt amperes with an exciter unit mounted on the main shaft. Fig. 25 shows the rotor element with the direct-connected exciter unit. Note the heavy-duty slip rings and the wedges holding the coils securely in the slots.

Armature Windings. The most important of several factors

which affect the arrangement of the windings used on an alternator are: (1) wave shape; (2) coil distribution; (3) winding costs; and (4) efficient generation of voltage. Some other features, such as number of poles and frequency, will be determined by the speed to be used, and will also have their effects on the armature windings.

The wave shape should approximate the sine wave, which would mean coil distribution up to certain limits. In order to obtain the required distribution to produce the desired wave shape, the coils must occupy several slots per pole per phase. These may be a whole number, but it is not necessary as 1½ slots per pole per phase may give a satisfactory wave form. Wave form is also frequently improved by using a fractional pitch winding. A fractional pitch winding is one which spans fewer slots than the pole covers which would make the coil sides somewhat less than 180 electrical degrees apart. This sometimes is reduced to .66 and even .5.

Distribution of windings makes better ventilation possible and helps reduce leakage reactance as well as improve the wave shape. However this is limited, particularly on high voltage machines, as more insulation must be used between layers in slots and less room is available for copper. End turns must also be more carefully insulated.

The cost of winding is an important item for consideration in constructing an alternator. Coils which can be formed and insulated before being placed in the slots very materially reduce costs and are better insulated. Form wound coils should all be the same shape. They require that the slots be open at the top, which reduces the efficiency of operation of the machine. However, these open slots may be closed or partially closed with magnetic wedges.

Efficient generation of voltage requires that the winding must be arranged so there is very little bucking action present. To avoid this trouble, the coils must be very nearly full pitch, that is, the sides must be approximately 180 degrees apart magnetically.

A careful analysis of the foregoing facts indicates that satisfactory winding of a machine will depend upon what is desired in the way of operating requirements such as wave form, efficiency and regulation as well as the first cost involved. Where conflicting variables occur, a compromise must be made which best meets the requirements. If the alternator is wound with three-phase windings,

these may be star- or delta-connected. In many cases there may be two independent groups of coils for each phase, especially with motor windings. Two sets of coils per phase make the machine easily converted into double normal voltage. A 220-volt connection can be made into a 440-volt winding by simply putting the groups in series.

Figure 26 shows a winding diagram for an alternator having 18

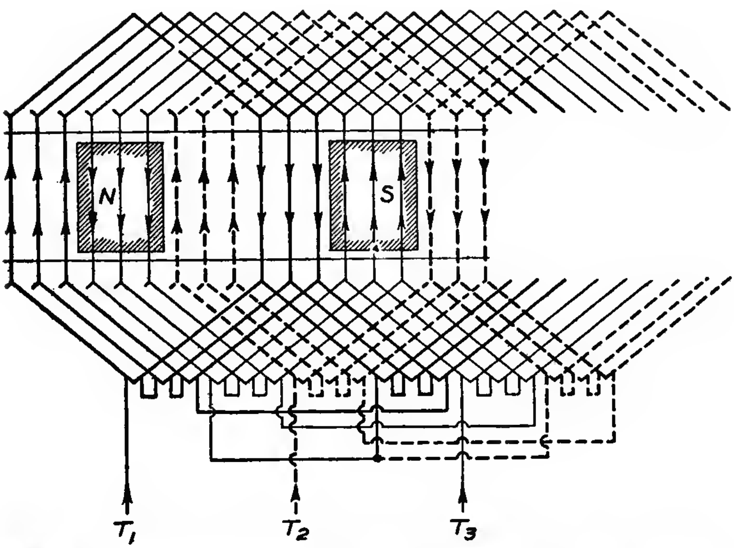


Fig. 26. Three-Phase Alternator Winding with 18 Slots, 18 Coils, 2-Pole Star-Connected

slots with 18 coils two-pole star-connected. This makes 6 coils per phase and 3 coils per pole per phase. The pitch is full being 1 and 10. Phase 1 is shown in light lines, phase two in heavy lines, and phase three in broken lines. This is a very simple connection and is shown to give the idea of the winding layout. In practice more coils would be used and the coils would be placed with sides of different coils in the same slot, as current directions are such in three phase as to permit this practice.

REVOLVING FIELD ALTERNATOR

The revolving field alternator is built in all types including the belt-driven, high-speed direct-connected steam engine, slow-speed type, Diesel engine, turbo-generator, and the water-wheel type.

Figure 27 shows a high-speed alternating-current generator made with either two or three bearings for belt drive or with one or two bearings where it is coupled to the prime mover. This unit is designed especially for use with oil, gas, or steam engine and built in capacities ranging from 12½ to 1250 kilovolt amperes 60-cycle with speeds from 514 to 1800 r.p.m. Note the open frame construction with the ducts at frequent intervals in the stator laminations. The air enters the machine through the end brackets, passes over the stator and field coils as well as through the stator core. This is accomplished by an ample system of ducts and baffles which prevents recirculation of the heated air. A sealed type of sleeve bearing, made oil, vapor, and dust tight, reduces bearing wear to a negligible amount.

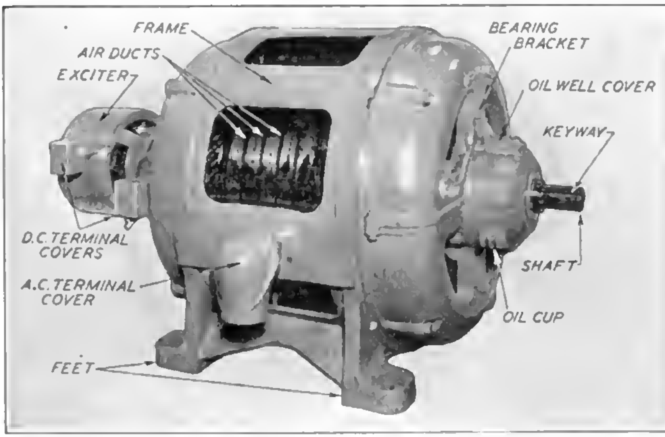


Fig. 27. Westinghouse Type G Alternating-Current Generator with Exciter Mounted on End of Generator

Stator. The stator frame of this machine is made of grey cast iron with the feet cast integral with the frame. The modern trend in all frame construction is toward rolled and welded steel frame construction. The core is built up with high-grade annealed steel sheet punchings dovetailed into transverse ribs in the frame. These laminations are compressed between end rings and keyed in place.

The coils are form wound from double cotton covered wire with the slot portions wrapped with fish paper and mica. This insulation is not affected by heat or moisture, and age has very little deleterious or harmful effect on its insulating qualities. Every stator is given a radio frequency test which indicates insulation defects on

individual turns. In this way the factory knows that each machine is free from defective coils. This defeats the chief cause of electrical breakdowns. Fig. 28 shows the high-frequency test being given to a large stator in process of construction.

Fig. 28. Testing Alternating-Current Windings with High-Frequency Alternating Current
Courtesy of Electric Machinery and Manufacturing Company

Rotor. The spider of the rotor is built up with steel punchings riveted together under hydraulic pressure. This core is then pressed and keyed to a steel axle shaft or a forged flange steel shaft for single bearing machines. The pole pieces are assembled from the electrical steel laminations riveted together under pressure. These poles are tightly dovetailed into rotor spider and keyed in position. The whole shaft and rotor is made with ample strength to withstand the variations in angular torque produced by Diesel engines.

The field coils are wound with copper straps or rectangular double cotton covered wire. As these are wound, an application of

insulating varnish is made to each layer and the whole coil is then impregnated with heat-resisting compound. Each coil is carefully insulated from the core and supports are provided to protect the coils against centrifugal forces and strains during operation. Fig. 29 shows a rotor used with the larger machines of this type. Note the damper winding provided near the pole faces to minimize hunting and variations in speed of certain types of prime movers. This addition to the rotor winding is almost a necessity where gas or

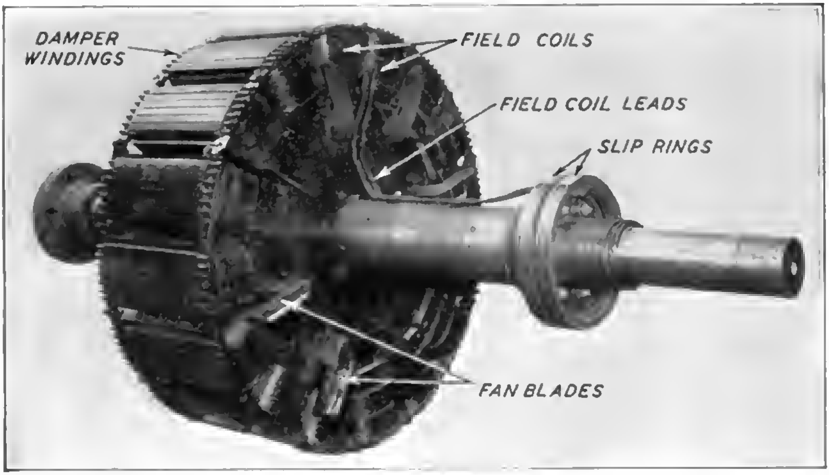


Fig. 29. Field Winding Mounted on the Rotor of a Large Alternator
Courtesy of Westinghouse Electric and Manufacturing Company

Diesel engines are used for motive power. Cast-iron collector rings are used almost exclusively on rotors magnetized from a direct-current source.

Exciters for these alternators are usually mounted directly to the frame of the generator with the exciter armature mounted on an extension of the rotor shaft. This eliminates the necessity for exciter bearings. In applications where direct-connected exciters are not desirable, any method of drive may be resorted to. Dual drive is frequently used in larger power houses with motor drive a highly favored method. Gas, steam engine, turbo, and water-wheel units are frequently used to power exciters. There are a few installations where V-belts are used from the main alternator shaft to the exciter.

SLOW-SPEED ENGINE-DRIVEN GENERATORS

The slow-speed generator is from necessity a massive piece of equipment with large weight per kilovolt amperes of output. Slow-speed machines require a larger number of poles to produce a given

Fig. 30. Engine-Driven Type of Alternator. The Shaft and Bearings are Built as Part of the Engine
Courtesy of General Electric Company

frequency than is required with high-speed machines. In order to accommodate a large number of poles, the rotor diameter must be increased over what is required in more rapid moving elements. With slow moving field poles, larger sizes must be provided to furnish the magnetic flux necessary to generate the proper voltage. This leads to longer stator coils with increased iron in the stator.

Figure 30 gives an excellent idea of a slow-speed alternating-

current generator used in direct connection to a steam or Diesel engine. The open style frame provides ample opportunity for good ventilation. The end shields are die formed and thoroughly protect the windings without interfering with air circulation over the stator coils. A pole piece for this generator is shown in Fig. 31. The damper windings are located in the slots in the face of this pole piece. The cores for these poles are assembled in the same manner

Fig. 31. The Pole of a Slow-Speed Engine Type Generator
Courtesy of General Electric Company

as other field poles but are drilled and tapped for pole bolts. These poles are slightly spiraled on the rotor spider in order to reduce magnetic hum when the machine is carrying load. The field coils are wound with rectangular double cotton covered wire, as this shape increases the copper area of the coil. The usual treatment is given the coil to properly insulate it.

These rotors are supplied with or without damper windings depending upon the operating requirements the machine must meet. When these are supplied, they are made from either brass or copper bars embedded in the slots of the pole face, fitted into holes in the end rings and silver soldered under red heat. The silver solder forms a strong low resistance connection and has exceptional penetrating qualities. To facilitate pole removal, the end rings are made in sections.

DIESEL ENGINE GENERATORS

The Diesel Engine generator is of the slow-speed heavy construction type similar to the machine just previously discussed. Due to the more recent development of alternators for this type of drive,

the frame construction is nearly all fabricated, rolled and welded. The speeds of these machines very closely parallel those for the slow-speed engine type ranging from 257 to 450 r.p.m. Somewhat more rigidity must be put into the rotor shaft on account of the tendency

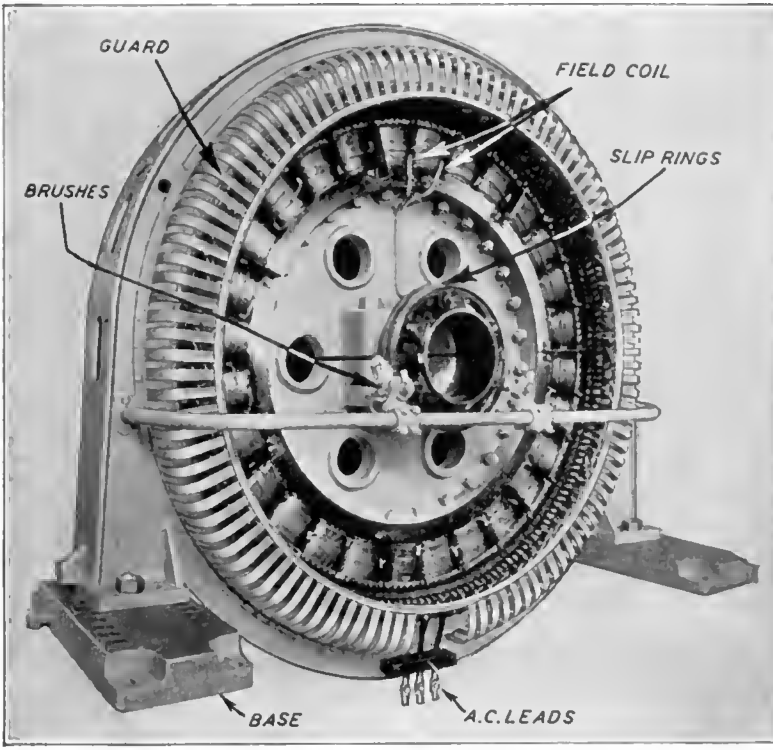


Fig. 32. A Large Slow-Speed Alternator to be Driven by a Diesel Engine
Courtesy of Electric Machinery and Manufacturing Company

of Diesel engines producing oscillating torque effects. Heavier damper windings are used on the poles to aid in smoothing out the engine torque when alternators are constructed especially for this prime mover. Fig. 32 shows a fabricated frame alternator built to operate with Diesel engine drive. Note the extremely heavy rotor flange to which the poles are bolted. The additional flywheel effect secured with this material is an aid to smoother operation of the unit. Even with the heaviest rotors, additional material is required to keep down the hunting tendencies of Diesel driven alternators. A heavy flywheel is usually provided

for this purpose. Fig. 33 shows a modern Diesel direct connected to an alternator with the stabilizing flywheel. Reciprocating steam engine driven generators have this same hunting tendency, but it is more pronounced in the Diesel so that heavier flywheels are required than are ordinarily used with steam units.

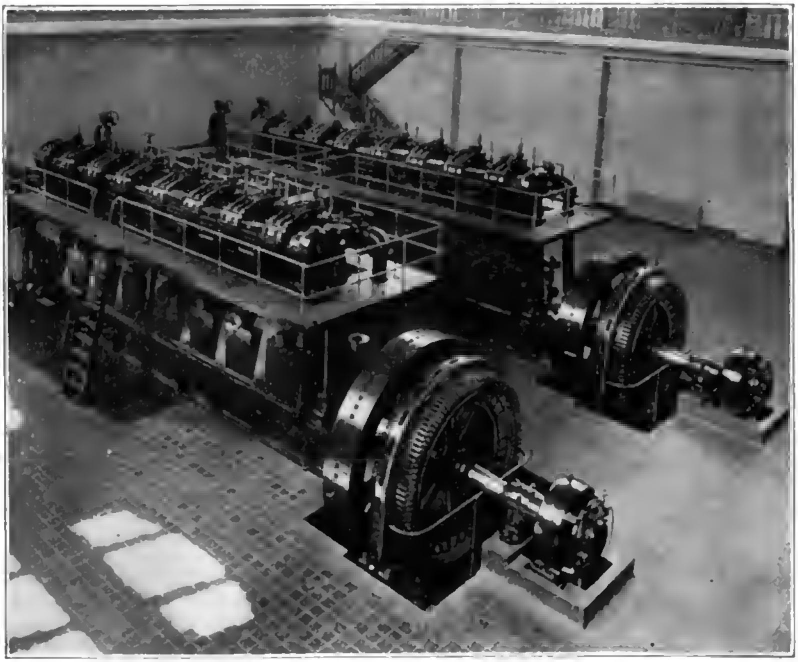


Fig. 33. A Diesel Engine Plant Consisting of Two Alternators with Direct-Connected Exciters
Courtesy of Electric Machinery and Manufacturing Company

TURBO-GENERATORS

Turbo-generators differ very materially in design and appearance from other types of generating equipment. The high speeds at which the rotating element operates requires a small diameter in order to reduce the stresses set up by centrifugal action. Noise and vibration set up by high-speed machines are muffled to some extent by totally enclosing the unit with sound deadening materials. In order to cool the equipment under these conditions, forced ventilation is resorted to. With the larger units this circulated air is washed and cooled before being blown through the alternator.

Many smaller units use reduction gears between the turbine element and the generator shaft. With geared units the generator can be of the standard belt-driven type. With capacities ranging from 10,000 up to 200,000 kilovolt amperes gearing would not be feasible. Fig. 34 shows a belt-driven type alternator connected to the steam turbine with reducing gears. Note the direct-connected exciter unit mounted on the alternator frame. Units of this particular type shown are made in capacities from 30 to 50 kilowatts.

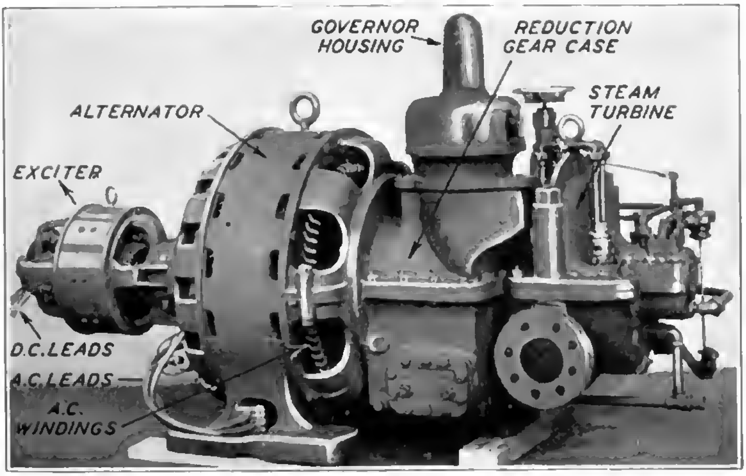


Fig. 34. A Medium Size Alternator Driven through Reduction Gears by a Small Steam Turbine
Courtesy of Westinghouse Electric and Manufacturing Company

The large high-speed direct-connected generators, Fig. 35, require a considerable change in the design from other types, especially in rotor construction. Note the totally enclosed features with arrangements for quick removal when cleaning and inspection are necessary. The pedestal-type bearing permits the rotor to be easily and quickly lifted from the stator with overhead crane should repairs be necessary on windings or bearings.

Stator iron and coil construction are not essentially different from other types of alternating-current generators. The iron is stacked so the slots are longer to accommodate the rotor poles. Coils are considerably longer with the straight sides imbedded in the stator slots wrapped with mica insulation. On account of the greater flexibility required at the ends of the coils these are wrapped with

treated cloth tape. Mica wrapped coils have greater dielectric strength, better heat conducting qualities, which improve reliability and efficiency for machines insulated with it. Better anchorage for the armature coils is secured through the use of insulated brackets. Adequate bracing is obtained by lashing the coils to these supports at frequent intervals.

Temperature detectors for checking the operating temperatures

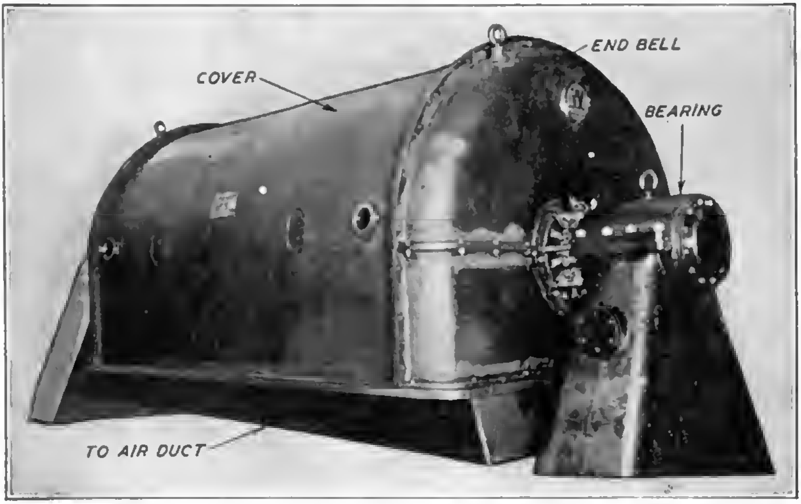


Fig. 35. A Large High-Speed Horizontal Turbo-Alternator Type of Generator
Courtesy of Westinghouse Electric and Manufacturing Company

are located in the stator slots at points where the heat is expected to be greatest.

The rotor, shown in Fig. 36, is machined from a solid steel forging. The slots for the field coils are machined radially to reduce noise from magnetic effects on the stator laminations. Field windings are made by forming continuous copper strip wound edgewise to form the coils. Metal wedges hold them securely in the slots. Mica strip is used between the conductors for turn insulation while moulded mica is placed between the coils and the pole piece. As the coils are made, each turn is given a treatment of special insulating varnish. The end turns are securely braced and the rotor is finally baked at a high temperature during which time it is subjected to a very high pressure applied through the use of clamping rings. This treatment eliminates air spaces and forces

all excess binding material so the whole coil becomes an almost solid homogeneous mass.

Collector rings are made from a tool steel forging. These are then shrunk on a mica bushing which insulates them from a steel bushing pressed on the shaft. All joints and connections to these rings are silver soldered at high temperature to prevent loosening up under normal operation.

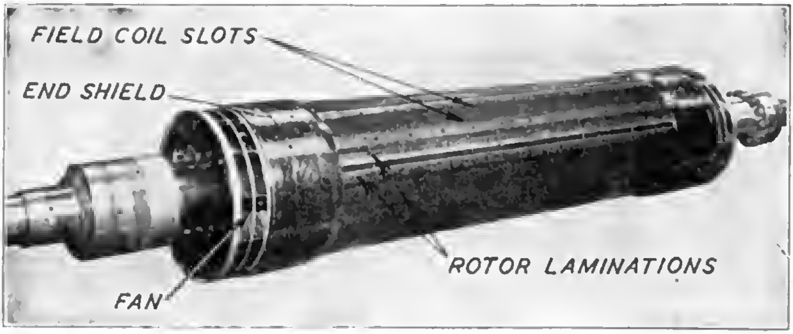


Fig. 36. Rotor of a High-Speed Turbo-Alternator
Courtesy of Westinghouse Electric and Manufacturing Company

WATER-WHEEL GENERATORS

Alternators for use with water-power units are made in both vertical and horizontal types. A far greater percentage of water-wheel driven machines are for vertical drive. The slowest speed machines made are driven by hydro units. The 9000 kilovolt ampere units at Keokuk are only 58 revolutions per minute and the 5000 kilovolt ampere units at Niagara run 250 revolutions per minute. The units for use with low heads of water run slower than higher head machines. Fairly high speeds are used on water-wheel units, 300 to 600 r.p.m. being common in capacities ranging from 10,000 to 20,000 kilovolt amperes. Next to turbine driven units the water-wheel generators are the largest constructed, as capacities as large as 22,000 kilovolt amperes have been built in horizontal type and 45,000 kilovolt amperes in the vertical type.

Figure 37 shows one of the large slow-speed water-wheel generators in operation at Muscle Shoals. The stator design of these large machines does not vary greatly from other types of alternating-current generating equipment. In some of the larger machines, the

section of the coil in the slot is treated with bakelite and hot pressed. This process makes a more rigid coil which is less subject to damage to the strand insulation while the coils are being assembled in the stator.

Duc to the wide range of speeds at which various water-wheel

Fig. 37. A 25,000 Kv-a. Vertical Water Wheel Type of Generator
Courtesy of Westinghouse Electric and Manufacturing Company

units operate, no single design of rotor will meet all requirements. For lower peripheral speeds a fabricated steel spider is employed as shown in Fig. 38. The poles are either bolted or dovetailed to the rim, Fig. 39. For the moderately higher speeds laminated steel or steel plate is used. The large relatively high-speed machines have a laminated rim, Fig. 40, to which the pole pieces are dovetailed. The coils for the rotor poles are usually double cotton covered magnet wire for the smaller sizes and strap wound for the larger units, as shown in Fig. 39.

Many smaller hydro plants have been made for full automatic operation. Thermal protection is provided in the winding and bearings through relays which fully protect the units against overload or oil failure. In case of a shutdown the machines will go through the sequence of starting operations three times. If at this time the

trouble has not cleared, an attendant must visit the plant and clear the difficulty before the machine can be operated.

MOTOR GENERATORS

Motor generator sets are made in practically all capacities from fractional horsepower units used for supplying radio sets to 7000

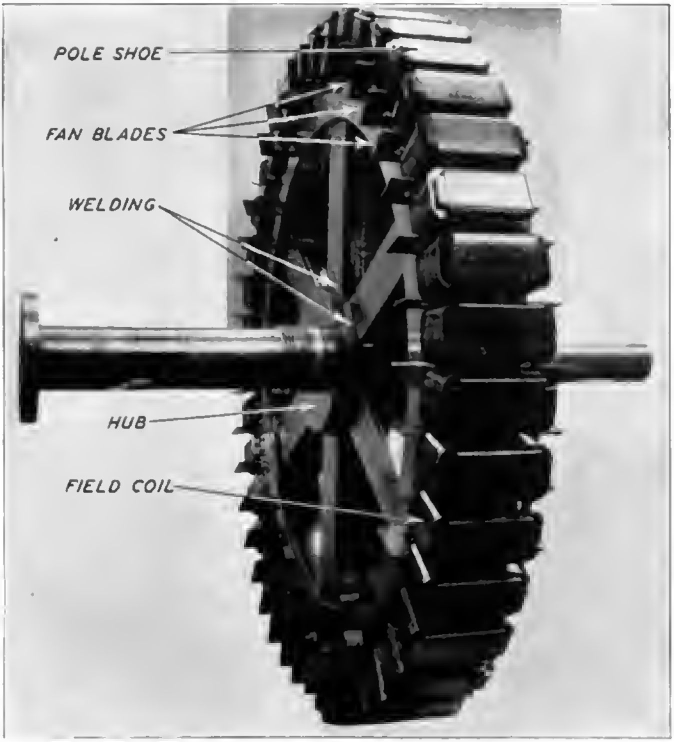


Fig. 38. A Rotor Built up by Welding Steel Plates and Angles. The Poles are Fastened to the Rotor by use of Dovetail Slots
Courtesy of Westinghouse Electric and Manufacturing Company

kilowatt sets used for large power applications. Some of these are used to convert alternating-current to direct-current while others change direct-current to alternating-current and some direct-current to direct-current where a change in voltage is desired.

A line of small motor generator sets has been made for producing alternating-current power to operate radio sets in locations where only direct-current power is available. Some of these were only 100

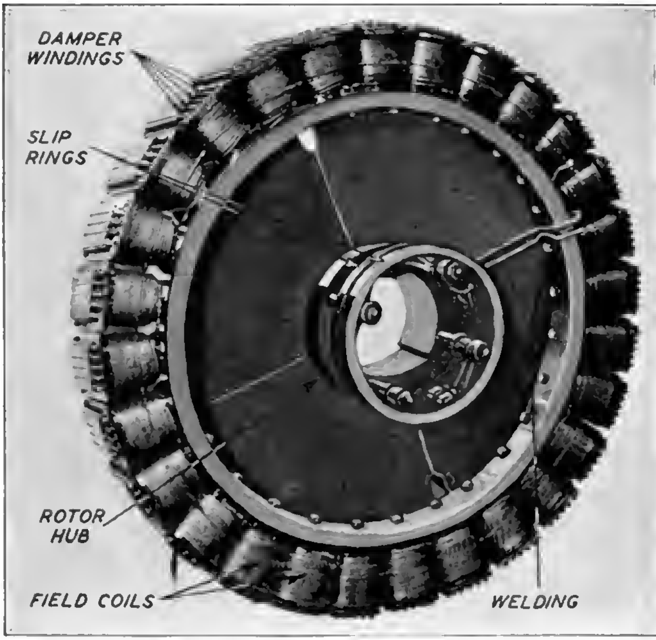


Fig. 39. A Large Rotor with Damper Windings and Pole Pieces Bolted to Rotor
Courtesy of Westinghouse Electric and Manufacturing Company

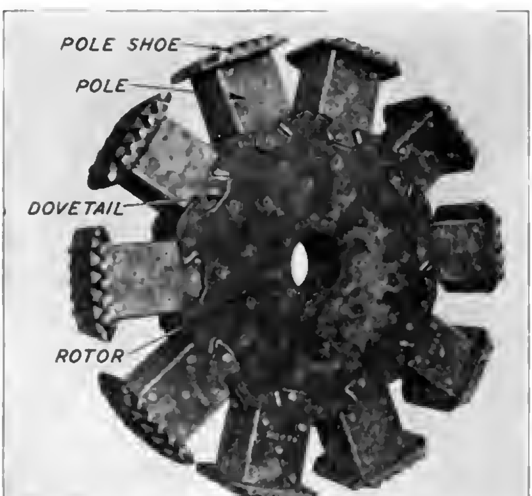


Fig 40. A Large High-Speed Rotor with Pole Pieces Dovetailed to It
Courtesy of Westinghouse Electric and Manufacturing Company

watts for isolated plant use, usually 32 volts direct-current to 110 volts alternating-current. Others for hotel and similar service were one kilowatt units and operated on 115 volts direct-current to 110 alternating-current. All the radio sets in one section of a building would be operated from a single unit. Motor generator sets are rapidly being replaced by converters as they operate more efficiently and cost less to build than do motor generator sets.

HIGH-FREQUENCY GENERATORS

A line of high-frequency generators which will vary the frequency from 60 to 240 cycles is made in capacities from 5 to 100 kilowatt. These machines are sometimes referred to as frequency changers, Fig. 41. A machine of this type can be made from a slip

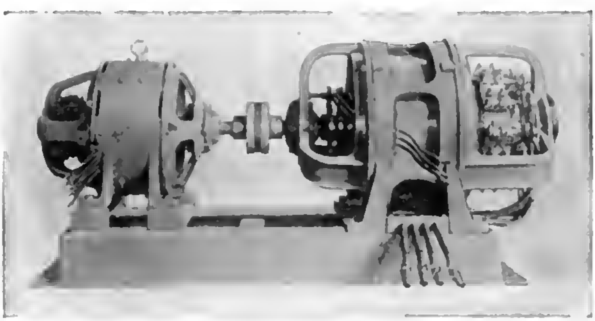


Fig. 41. A Motor Generator Set. An Adjustable Speed Direct-Current Motor Is Driving an Alternating-Current Generator
Courtesy of Reliance Electric and Engineering Company

ring motor preferably driven by a variable speed motor. The stator of the slip ring motor is connected to the line and the motor to be driven to the slip rings. The variable speed motor drives the rotor of the slip ring motor in the opposite direction from which the stator currents would rotate it. This will produce frequencies from the line frequency up to three times line frequency by 50 per cent over speed in the rotor; thus a 4-pole 60-cycle slip ring motor driven at 2700 r.p.m. will produce 180 cycles. A 2-pole motor connected to this frequency changer would have an operating speed of 10,800 r.p.m. Woodworking plants frequently require high-speed motors, and motor generator sets, arranged as described, produce the necessary speeds.

Machines have been made for producing very high frequencies, some as high as 500,000 cycles for operating induction coils. At the present time all new high frequency circuits are operated from oscillations set up by vacuum tubes. This method is proving so satisfactory that motor-generator machines are no longer advertised for this purpose.

TYPES OF ALTERNATING-CURRENT MOTORS

Two or more magnetic fields are always required in either direct- or alternating-current motors to produce torque. These fields set up magnetic poles which act upon each other through attraction or repulsion to produce the rotating forces called torque. The construction of the machines for utilizing direct current are quite different as a rule from those using alternating current to produce these magnetic forces.

The stationary field and revolving armature, with most of the line current passing through brushes to the moving element, is almost universally used with direct-current motors. The alternating-current motor has practically the reverse arrangement, as this machine nearly always has the main line current passing through stationary windings. This current passing through these windings sets up a revolving field which acts on the rotating element in various ways with different types of motors to produce torque. How this is accomplished in the various types of alternating-current motors will be explained in the discussion of each. The important points of difference to bear in mind are these. The direct-current motor has stationary poles and a revolving armature, while the alternating-current motor has stationary coils with rotating field flux. The stationary part of a direct-current motor is called *the field* and the moving element *the armature.* The stationary part of the alternating-current motor is called *the stator* and the moving element of the motor is called *the rotor.*

SPEED OF ALTERNATING-CURRENT MOTORS

The speed of a direct-current motor can be easily changed by raising or lowering the applied voltage or using resistance in either the armature or the field circuit, wide ranges of speeds being obtainable with the direct-current motor through this means. Only very limited speed ranges are possible with alternating-current motors. One of the elements producing torque in the alternating-

current machine is the revolving field. No rotor of an induction motor can revolve faster than this field rotates. The top speed of a motor on an alternating-current circuit then becomes the synchronous speed of this revolving field. More about this fact will be discussed under each type of motor.

The speed of this rotating field is determined by the number of poles and the rapidity with which these change from north to south. The frequency which is determined by the number of changes of polarity in the poles depends upon the number of cycles per second obtained from the alternator supplying power to the circuit. A 2-pole motor connected to a 60-cycle source would have 60-pole changes each second for each pole which would make 3600 changes per minute. Therefore, the stator field would rotate at a synchronous speed of 3600 and would limit the rotor speed to a like amount. If the stator was wound with four poles instead of two, the rotor would advance only one-half a turn for each cycle of change; hence, two cycles would be required on the stator to turn the rotor one complete revolution. Thus with a 4-pole stator the rotor speed would be 1800 revolutions per minute or one-half what it was with a 2-pole stator. A stator wound with six poles would require three complete cycles or pole changes to make one complete turn of the rotor. Mathematically the synchronous speed of a rotor would be

$$\text{r.p.m.} = \frac{\text{cycles} \times 60 \times 2}{\text{number of poles}}$$

Sixty is used because there are 60 seconds in a minute and two must be used because it requires a pair of poles, one for each half cycle, to make the magnetic circuit. If the frequency was changed from 60 to 40, the speed at which the poles would change polarity would shift the same amount. A 60-cycle motor on a 40-cycle circuit would run at only two-thirds its former speed. Note—this is not a practical thing to do but is used merely for illustration. A motor under these conditions would run hot because of lack of iron in the magnetic circuit for the lower frequency.

It is well to note at this time that the number of phases of the circuit supplying the motor has nothing to do with the speed at which it operates.

SINGLE-PHASE MOTORS

Single-phase motors may be classified according to the three following groupings: (1) series; (2) induction; and (3) repulsion. Taken as a whole the induction type is much more numerous than the others although certain fields of application may be almost wholly supplied with one type. The small motor-driven tool and appliance industries use enormous quantities of series type motors, with some companies making a specialty of this particular motor. The induction type is used in practically all applications where constant speed is desirable, as this motor is like the shunt in this characteristic. The repulsion motor provides better starting than the induction type and is also widely used where variable speed is required from an alternating-current source of power. Many types of repulsion motors have been developed, over half of which are now obsolete. Practically all companies making alternating-current machines make a repulsion motor. Some of these are discussed later in this lesson.

Torque. An induction motor may have running torque but has little or no starting torque. Why this condition exists is explained by Fig. 1. A squirrel cage rotor is used in this illustration as it simplifies the diagram, and the theory is exactly the same whether the armature is wire wound or made up from short-circuited bars. Fig. 1 shows a 2-pole stator with single-phase winding connected to lines L1 and L2. During one-half cycle the current is flowing into the stator winding from L1. This makes the top half of the stator a north pole and the lower half a south pole.

The flux in the stator, set up by the current during the first half cycle, will cut the rotor bars and induce currents in them as shown in *A*, Fig. 1. As these bars are short-circuited by end rings, currents will flow in the bars and cause the rotor to be polarized with a north pole, N, at the top and a south pole, S, at the bottom, as in *B*, Fig. 1. This position of the rotor poles with reference to the stator poles with north pole N at the top and south pole S at the bottom will produce no torque in the rotating member because the rotating forces are equal and in opposite directions.

During the next half cycle the polarity conditions of both stator and rotor will be exactly reversed and no starting torque will be produced.

As long as the rotor and stator poles have this relationship, no torque can be developed, because some angular displacement of the rotor and stator pole positions must take place before any turning action becomes effective. How this displacement of the poles on the stator and rotor is effected for starting will be explained under split-phase motors.

The single phase motor differs from the polyphase motor in

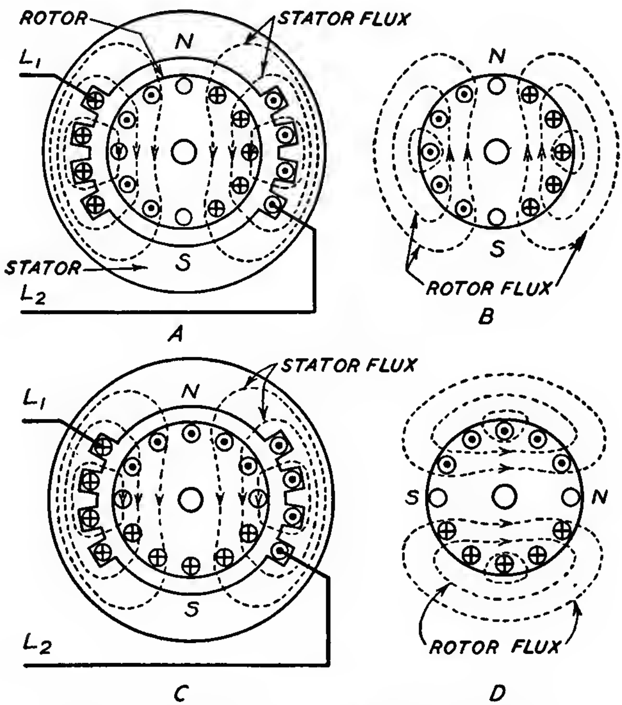


Fig. 1. Direction of Flux Paths in Stator and Rotor

the following respect. The poles alternate in the single phase machine while the stator flux rotates when more than one phase is used.

Figure 1, *C* and *D* shows the relative positions of stator and rotor polarities when the rotor is driven at synchronous speed in the changing field of the frame. In the case of a two-pole motor, the rotor would have to be turned once for each cycle. This rotation of the moving member causes the polarity to be at right angles to the stator poles. The main poles are located at the top and bottom while the induced poles are on the right and left sides of the rotor.

This is the position which produces the maximum torque. Just why the rotor poles are now at right angles to the main poles is rather difficult to understand. This shift of poles from positions in Fig. 1 to the positions they now occupy is caused by the rotor rotation.

Figure 2 shows the stator flux polarity on the second half of the cycle resulting from the current supply furnished by L_1 and L_2. This figure shows the rotor flux condition at very nearly synchronous speed. The rotative affect has now caused the rotor polarity to shift almost 90 degrees with reference to the stator polarity. A comparison of Fig. 2 with Fig. 1 will clearly indicate this fact.

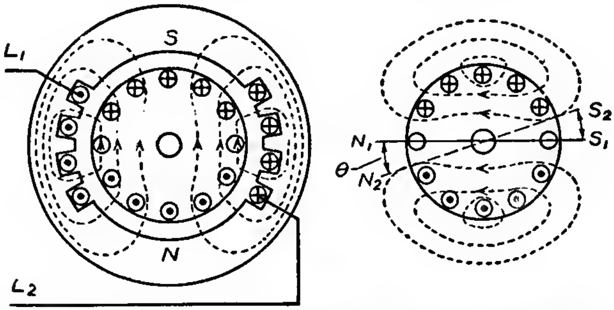


Fig. 2. Direction of Flux when Stator Current Is Flowing from L_2 to L_1 and Rotor Running at Synchronous Speed

This relationship of rotor pole position with stator pole position results in maximum available torque. The angle Θ between the true 90 degree position and the actual pole position is caused by the slip. In any motor where the rotor field is produced by the flux of the stator setting up a voltage in the rotor winding, the revolving or changing field must rotate faster than the moving element of the machine. Otherwise, no flux could cut the rotor and no voltage would be produced to force current through the circuits in the armature of the machine. This difference in speed between the revolving field and the rotor is called the slip. This usually varies from two to seven per cent on well-designed squirrel cage machines. It is seldom over four per cent on three-phase motors of this type.

Series or Universal Motor. Figure 3 shows the diagram for a series or universal type of single-phase motor. This machine is almost identical with a direct-current series motor. The alternating-current conditions require that these machines have laminated iron pole pieces as well as the laminated armature. This construction

eliminates eddy currents in frame and pole pieces. In this motor both the stator and the rotor are magnetized from the line current.

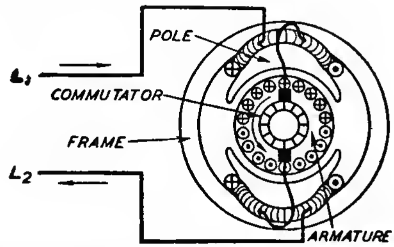


Fig. 3. A Series on Universal Motor with Current Flowing as Shown by Arrows

When the current reverses in one part of the machine, it reverses in the other at the same time. This means that the operation with alternating current is essentially the same as though direct current was operating it. Fig. 4 shows the conditions in the series diagram in Fig. 3 on the second half of the cycle only. The direction of the current is reversed, but the polarity relationship between the armature and the stator are relatively the same so the torque is developed regardless of the current direction through the motor.

Thus, it is very essential that the direction of magnetism in the field and armature reverse at the same exact instant, because if one reversed first the direction of the torque would be reversed momentarily.

Universal motors will have somewhat different load speed characteristics on direct current than on alternating current. The inductive effects present in the alternating-current circuit will cut down the current and reduce the speed below what it would be on a

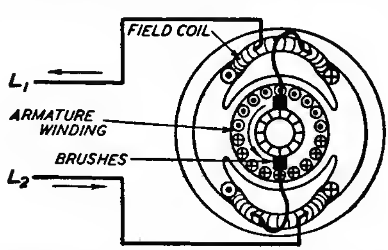


Fig. 4. The Direction of Current Flow One-Half Cycle Later Than in Fig. 3

direct-current circuit of the same voltage. Motors of this type are used principally on small appliances such as drills, scrubbers, blowers,

vacuum cleaners, sewing machines, mixers, etc. To meet these types of service, capacities from 1/150 to 1 horsepower have been developed. Universal motors have high starting torque and operate most efficiently at speeds of 4000 to 10,000 revolutions per minute, speeds possible only with small armatures. Fig. 5 shows the parts of a universal motor just described.

Many applications where universal motors have been tried show

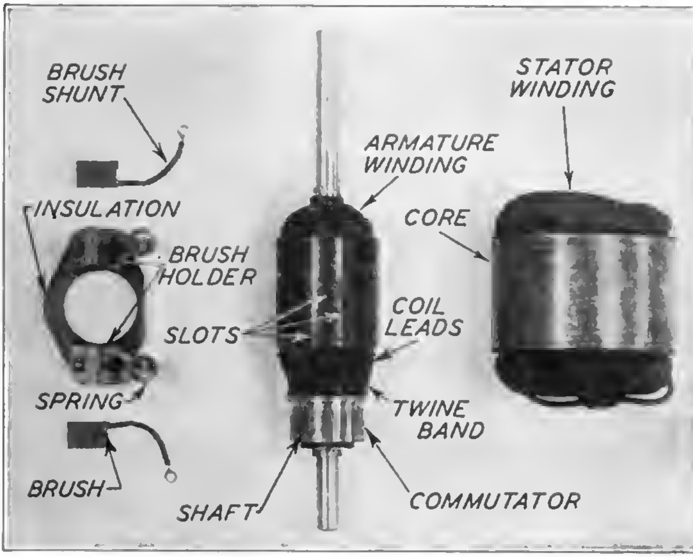


Fig. 5. Parts of a Westinghouse Type AD Universal Motor

unsatisfactory results on account of the wide difference of the speed behavior of the motor when operating on direct and alternating current. To meet this condition, many concerns make two motors, one of alternating-current and the other for direct-current use. These are interchangeable so far as dimensions are concerned. This development indicates that considerable judgment must be used in universal motor application.

Larger capacity universal motors require an additional winding on the stator to cut down the high inductive effects at the brushes. This winding, called a compensating winding, is wound so that its field will neutralize the field of the coils being commutated, thus helping to reduce abnormal sparking. This would make the compensating winding 90 degrees from the main or stator windings. It

is connected in series with the main winding and armature. The high resistance of the small motor coils takes care of the inductive effects on small machines, but the low coil resistance and higher voltage usually used aggravate sparking at the brushes on larger motors of this type requiring a neutralizing winding to enable the machine to operate satisfactorily.

Series motors used on alternating current have considerable advantage over direct-current series motors. Through the use of a transformer with a number of taps on the secondary, the voltage at the motor terminals may be efficiently changed. This variation of the motor terminal voltage provides a wide range of speeds obtainable with the alternating-current motor.

A large universal motor has been successfully developed for railway work. The direct-current voltage of 550 volts is used from the trolley on city streets and 1300 volts can be used from a transformer when the car runs in interurban territory. This motor gives very satisfactory operating characteristics on either system and is widely used for this type of work.

Split-Phase Motor. The split-phase motor is a squirrel cage motor with two windings on the stator, one of which is the running winding and the other the starting winding. A glance at Fig. 1 shows the conditions in the stator and rotor magnetic circuits with the like poles on each, exactly opposite, producing no starting torque. One of the most common methods of obtaining a displaced polarity condition between the rotor and the stator fields, to bring about torque for starting purposes, is to add another set of coils to the stator as shown in Fig. 1.

These coils are wound 90 degrees from the original set and are connected to the power circuit only during the period of starting. The leads to this switch are disconnected from the line by a centrifugal switch as soon as the motor reaches about 85 per cent of synchronous speed, and remain off the line until the speed drops to approximately 60 per cent of normal when they will be cut in on the line again by the switch. Unless the speed comes up to normal in a short time after the reduced speed, this winding may burn out.

The running winding *R* shown in Fig. 6 is the same winding as shown in Fig. 1. The starting winding *X* is wound between the coils of the running winding *R* and has high resistance and low induc-

tance while R has a low resistance and high inductance. This will give the two windings a phase displacement of the two currents flowing in the running and starting coils approximating the conditions in a two-phase circuit. Instead of the polarity of the stator winding shifting 180 degrees and changing the polarity of the main winding to a like amount, this additional set of coils causes a shifting of the magnetic flux only 90 degrees for a half cycle change in current.

In Fig. 7, consider R the running winding to be phase 1 and the starting winding X to be phase 2. The current in R is at a maximum value positively while the current in X is just ready to start

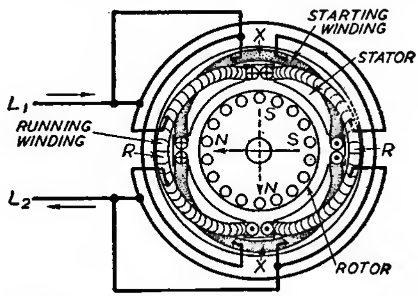


Fig. 6. Diagram of a Single-Phase Motor with Starting and Running Windings

positively. As the current in R gets smaller, weakening its magnetic effect, the current in X is getting larger, strengthening its magnetic effect. The result is a polarity which moves around the rotor in a clockwise rotation.

This in effect is a rotating magnetic field around the rotor which cuts the rotor bars setting up local circuits in this element, polarizing it. These magnetic poles set up in the rotor tend to follow the main poles and a starting torque is produced. While this torque is weak compared to the running torque developed, as the rotor approaches synchronous speed, it is sufficient to start light loads found in many types of motor applications where fractional horsepower motors are used.

Split-phase motors are made only in fractional horsepower sizes for use where small amounts of power are needed from a single-phase lighting circuit. The starting torque is too low to start only very light loads, and the starting current is high, which causes line voltage disturbances. In some applications, a clutch disconnects the motor

from the load until it is up to speed where it has normal torque.

Condenser in One Leg. Some split-phase motors are wound with two sets of coils like a two-phase motor as shown in Fig. 7. As the currents in coils *R* and *X* normally would be in phase from a single-phase source, resistance and capacity are introduced in coil *X*. This causes the current in coil *X* to lead the voltage which would result in a phase angle between the currents in the two coils. The resulting magnetic poles moving around the stator would develop starting torque, and the motor would operate very similar to a two-phase machine. This type of starting for split-phase motors is more expensive than starting winding with the switch, but it improves

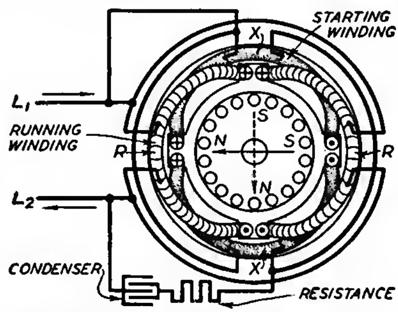


Fig. 7. Method of Connecting a Condenser and Resistance in a Split-Phase Motor

power factor, efficiency, and slip, as this motor acts more like a polyphase induction motor.

In order to increase the effectiveness of the condenser for starting, in some cases an auto transformer is used to raise the voltage across the condenser terminals to three or four times normal. The condenser is sometimes left in the circuit with line voltage across the terminals while the motor is operating, as this improves efficiency and power factor of the motor.

Figure 8 shows a capacitor-start induction-run motor for use in refrigerators, stokers, oil burners, and other household appliances where higher starting torque is required than is obtainable with the split-phase motor. There is also less radio disturbance from this motor than is caused by the split-phase machine.

Reactance in One Leg. Reactance may be used in one leg of a two-phase winding for starting on single phase. This consists of a choke coil connected in one phase of the winding on the stator.

This lagging of the current in one phase caused by the choke makes displaced phase relations between the currents in the two coils on the stator windings which sets up the starting torque in the rotor. In some cases a choke is used in one leg as a current limiting device when the condenser is utilized for starting. This tends to limit line disturbance but cuts down the starting torque of the motor.

Fig. 8. Wagner Single-Phase Induction Motor with Electrolytic Condenser Mounted on Top

Resistance Wire. The use of resistance wire in the winding of the stator has been used in a few small motors to obtain this split-phase condition for starting. A few coils of resistance wire have been interspersed in the main winding to produce starting torque. Motors of this type have usually been fan motors in which efficiency is a minor item in the operation. Better methods have been developed which have made this type of construction nearly obsolete. High resistance leads, from the coils to the commutator segments, are sometimes used with single-phase straight series motors to reduce sparking which is especially bad during the starting period.

Squirrel Cage Rotor. Practically all motors of the split-phase type, now being manufactured, use the squirrel cage rotor and the wound stator, as this method of construction has proved much superior to the reversed scheme of the squirrel cage stator and the wound rotor. Fig. 9 shows clearly the main windings, the starting

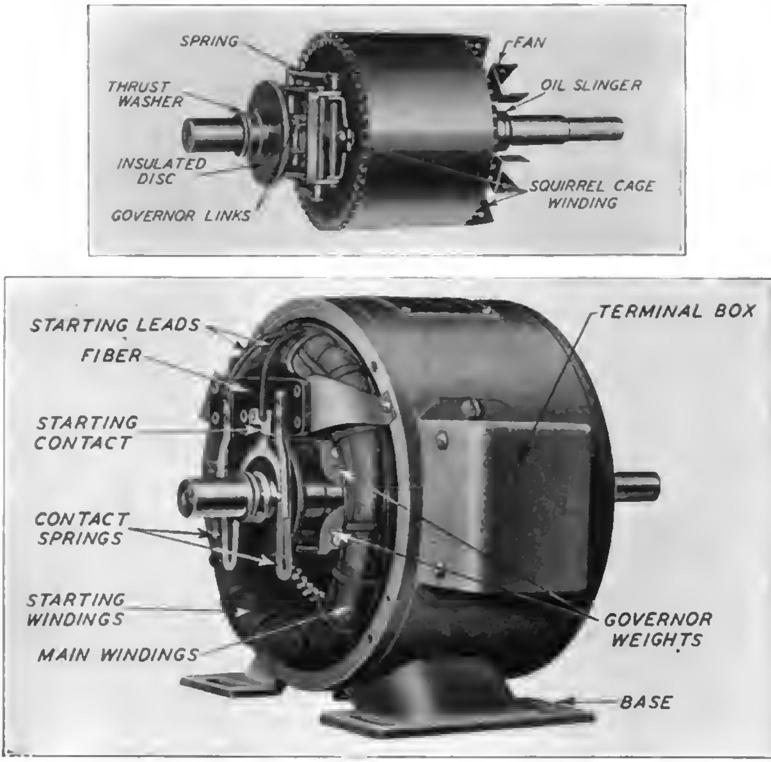


Fig. 9. (Top) Rotor of Century Split-Phase Motor Showing Governor Which Opens Starting Windings
(Bottom) Rotor Assembled in Stator Showing Arrangement of Open-Circuiting Device
Courtesy of Century Electric Company

windings, and the open circuiting switch operated by the rotor of a motor of the split-phase type.

Split-phase motors with the squirrel cage stator and the running and starting coils on the rotating member were made quite extensively by the General Electric Company up until a very few years ago. Due to the fact that the coils could be machine wound, the cost of construction for this type of motor was very low and therefore large

quantities of these motors were sold. The construction shown, Fig. 10, required the power supplied to this machine to be passed through the carbon brushes to the bronze rings as shown on the rotor. Trouble was experienced from brush and ring wear with the resultant sparking causing considerable radio interference.

There are two classifications of alternating-current commutator motors—those in which the speed materially changes with the load are called series motors, and the others in which there is only a slight change in speed with load are termed shunt motors. The latter type

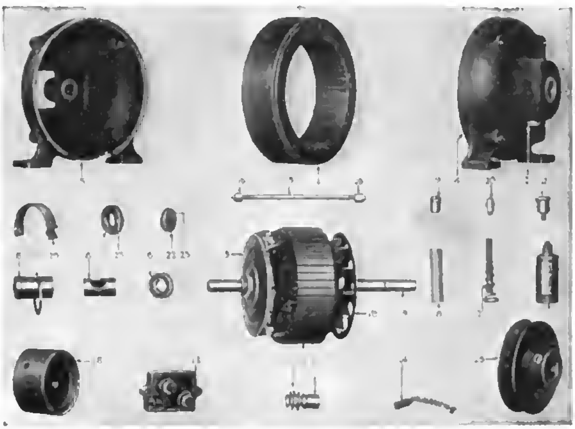


Fig. 10. General Electric Type SA Single-Phase Rotor

may be connected with auxiliary equipment which provides a variable voltage through which the speed may be increased or decreased independently of the load. They are still classified as alternating-current shunt motors however. Many of the repulsion type motors discussed later in this lesson fall in the latter classification.

Repulsion Motor. The repulsion motor has the stator coil connected to the line. The armature is wound like a direct-current machine but has no connection to the line. Short-circuiting brushes provide an armature circuit which has an electromotive force across it because of the magnetic effects of the stator winding. The poles set up by the induced current in the rotor are the same polarity as the stator poles. The torque is set up by the opposing forces between these sets of like poles from which comes the name *repulsion motor*. A series motor, with the stator winding connected to the source of supply and the armature short-circuited, would become a motor of

this type. The repulsion motor finds a wide field of application where comparatively high starting torque is essential. A great many modifications have been made of the original repulsion motor developed by Elihu Thompson as early as 1887. Fig. 11 shows a diagrammatical representation of this early motor. The armature is provided with a pair of brushes for each pair of poles on the stator

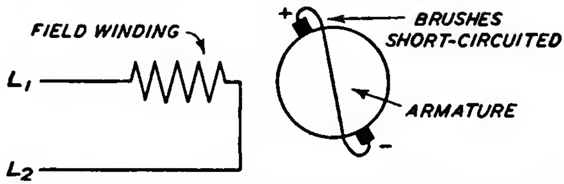


Fig. 11. Diagram of Circuits in the Early Repulsion-Induction Motor

winding. All positive brushes are short-circuited with all negative brushes.

Currents developed in the rotor, through the action of the stator flux, will develop torque in any position of the brushes between poles except at the halfway point. Here as much rotative effort will be developed in one direction as the other; therefore, the result will be zero and no torque will result. This is made clear from an inspec-

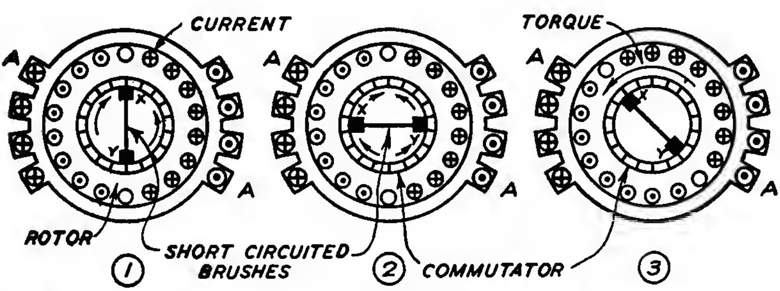


Fig. 12. Diagram Showing the Direction of Induced Voltage, Current, and Torque in a Repulsion Motor

tion of Fig. 12. This shows stator coil *A* setting up a magnetic field across the rotor which changes polarity with the frequency of the supply circuit. This induces an electromotive force in the rotor windings. With brushes as in position (1) the electromotive force developed in the right side of the rotor will be exactly equal and opposite to electromotive force in the left side of the rotor. With

brushes set at the position where these electromotive forces meet, a large current will flow, but no torque will be developed because the turning effort on the two sides of the rotor balance each other. If the brushes are now moved into position (2), we have a condition of balanced voltages across the brushes as shown by the two sets of arrows and no current flows through the short circuit. With brushes

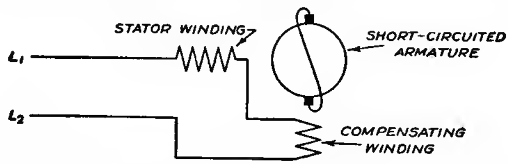


Fig. 13. Diagram of Circuits of an Atkinson Repulsion Motor

in position (3), the condition of unbalanced voltage would cause current to flow through the short circuit and the turning effort would be more in one direction than the other, so useful torque would result causing the rotor to turn.

ATKINSON MOTORS

The Thompson or original repulsion motor worked satisfactorily as long as lower voltages and small sizes were made. When larger sizes were made and higher voltages were applied to these motors,

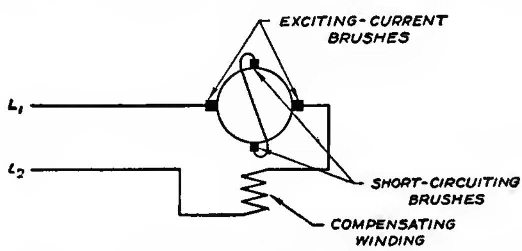


Fig. 14. Diagram of Circuits of Latour-Winter-Eichberg Repulsion Motor

a great deal of commutator trouble developed from the large inductive effects on the short-circuited coils. The compensating winding was found to be a satisfactory solution for this trouble in the alternating-current series motor, so Atkinson applied the idea to the Thompson motor. The result is the conductively compensated repulsion motor shown in Fig. 13. Another variation of the compensated single-phase repulsion motor is shown in Fig. 14. This

motor employs two sets of brushes, one to pass the line current through the armature like a series motor and the other to short-circuit the armature to produce the repulsion effect. This idea is jointly credited to men by the names of Latour, Winter, and Eichberg.

The advantage of the last arrangement is in the elimination of the stator coil; the armature winding is made to furnish this field more effectively than was the case with a stator winding.

All of the repulsion motors discussed have the direct-current series motor characteristic of losing considerable speed as the load is applied.

REPULSION-START INDUCTION-RUN MOTORS

The repulsion-start induction-run motor is by far the most numerous of all the various types of single-phase motors. This machine has the operating characteristics of the induction motor with starting torque from two to five times full load running torque. For the same line current it has higher starting torque than any other type of single-phase motor. Its maximum torque varies from 2 to 2½ times full load torque and its pull in torque from 1½ to 2¼ times its full load value.

The stator is usually wound with two sets of coils which makes possible the use of the motor on either 110 or 220 volts by simply connecting the coils in parallel or series. The stator core is high-grade steel laminations riveted together under pressure. The cores of these machines are usually insulated and completely wound before being inserted into the frame. This type of construction makes repairs simply and quickly made, as a spare core may be kept on hand to replace burn outs.

Frames are usually rolled from steel sheets, as this provides greater rigidity with less weight than is possible with cast frames. The feet are welded to the frame. Various types of vibration absorbing bases are available for special applications where noise is objectionable. Some of these use steel spring mountings and others are set in rubber.

The armature for repulsion-start induction-run motors is made of laminated iron and wound with coils like a direct-current or repulsion type machine. The commutator is provided with a short-

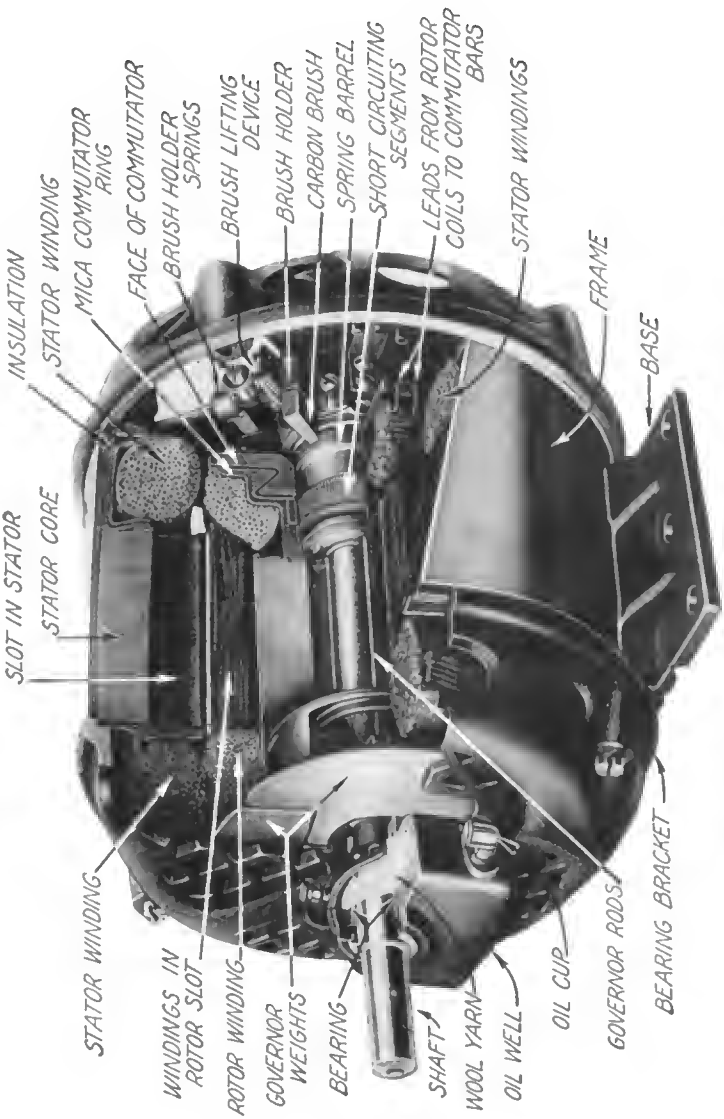


Fig. 15. Cutaway Section of Century Repulsion-Start Induction Motor

circuiting device which short-circuits the coils and makes the machine function like a squirrel cage induction motor once it is up to speed. The short-circuiting device is operated by a centrifugal switch which forces a copper ring, made of small segments, against the commutator bars after the proper speed is reached. This is usually about 80 per cent of synchronous speed but varies with different motor manufacturers.

End type and ring type commutators are both used with repulsion-start induction-run motors. Some are made to throw the

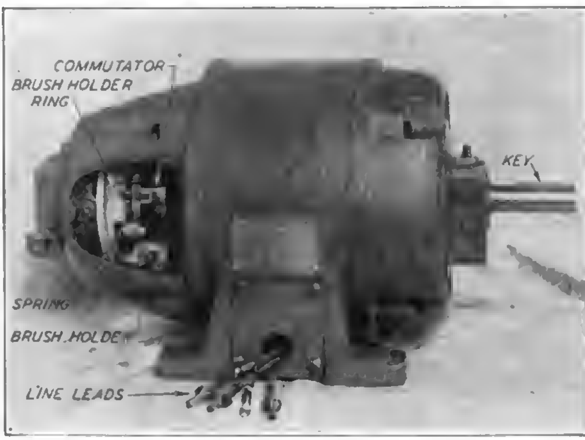


Fig. 16. Westinghouse Type CR Induction Repulsion-Start Motor

brushes clear of the commutator, while others ride the commutator continuously. No matter what commutator type or brush riding arrangement is used, all of them short the commutator to make the rotor function as an induction machine while operating. During the starting period, the line current either passes through the armature as in Fig. 13 or excites the armature through induction as in Fig. 12, producing like poles on both rotor and stator. The repulsion effect sets up the high starting torque characteristic of these motors.

Figure 15 shows cutaway section of a repulsion-start induction-run motor built in sizes of 1/8 to 40 horsepower. This machine has the end commutator with brush lifting rigging used in a very large percentage of these motors. Fig. 16 shows a motor with the ring type commutator on which the brushes ride permanently but carry

current only during the starting period. These machines are built in capacities from $\frac{3}{4}$ to 3 horsepower.

Some of these motors are built with an inner squirrel cage winding which improves the torque curves of the straight repulsion-start motor. The outer winding connected to the commutator provides the initial starting torque and assists the inner squirrel cage winding by carrying its share of the rotor current while running. This construction provides a motor with very smooth-speed-torque curve with sufficient torque to bring up to speed any load it can start. The speed is nearly uniform from no load to full load.

Repulsion-start induction-run motors are used for a great variety of purposes, a few of which are given as illustrations: compressors; pumps; farm machinery; ventilating fans; blowers; machine tools; grease guns; car washers; lifts; oil burners; and refrigerators. Wherever there is a difficult power job to be done and only a single-phase source available, this type of motor will nearly always be found taking care of it.

GENERAL ELECTRIC REPULSION-INDUCTION MOTORS

The General Electric Company make single-phase repulsion-induction motors with two types of compensating windings. One type has an independent compensating circuit, while the other takes a tap from the main stator winding to neutralize induction. Both of the motors are a modification of the original Thompson motor. The compensating circuits used in this motor improve not only the power factor but also the speed characteristics of the original motor, both of which were very poor. This motor is not a constant-speed machine but is designed to approximate the speed characteristics of a compound direct-current motor. The starting torque varies from 2 to $2\frac{1}{2}$ times full load torque. It may be connected directly across the line, but a resistance type starting box may be used if direct starting causes too much line disturbance.

The brushes ride the commutator at all times, and the motor may be reversed if the brushes are rotated far enough in any one direction. This motor is built for reversing by using a switch and adding another winding to the stator at 90 degrees to the original one. Whichever direction the current flows through this winding, with reference to the original stator winding, will determine the direction

of rotation of the motor. There are two ways of obtaining adjustable speed for these repulsion-induction motors. The brushes may be shifted, or through the use of a transformer with taps which changes the terminal voltage. For some applications, both the transformer with taps and a brush shifting device are employed to obtain adjustable varying speeds. Fig. 17 shows a motor of this type for operation on either 110 or 220 volts with a speed variation of $2\frac{1}{2}$ to 1. It is

Fig. 17. Single-Phase Motor in Which Speed Adjustment Is Obtained by Shifting Position of Brushes
Courtesy of General Electric Company

either reversible or not reversible as required in sizes varying from $\frac{1}{4}$ to 2 horsepower.

The starting torque will vary with the brush position and will be from $1\frac{1}{2}$ to 3 times full load torque for 4-pole motors and from $1\frac{1}{4}$ to $2\frac{1}{2}$ on 6-pole motors. The maximum torque obtainable from this type of motor will be approximately $3\frac{1}{2}$ times full load torque. Because this is a constant torque motor, the horsepower output will be proportional to the speed. The no load speed of this motor is about 1.6 times synchronous speed. Unless the motor is properly loaded the speed variation will not be obtained as the series characteristics will over speed it. Its principal fields of application are in the operation of printing press machinery and testing equipment.

A larger motor for use on polyphase distribution systems is shown in Fig. 18. It can be obtained regularly in 3 to 1 speed ranges but is also available in other speed ratios. These motors have shunt

field characteristics which open a wide field of application requiring any number of speed variations. A few examples of the various lines which are powered by these motors are as follows: baking machinery; boiler-house fans; cement kilns; centrifugal compressors and pumps; conveyors; laundry ironers; oil refinery equipment; paper winders; stokers; textile machinery; and rubber working plants.

CENTURY REPULSION-INDUCTION MOTORS

The Century is not a repulsion-induction motor in the same sense that the General Electric motor is a repulsion-induction type.

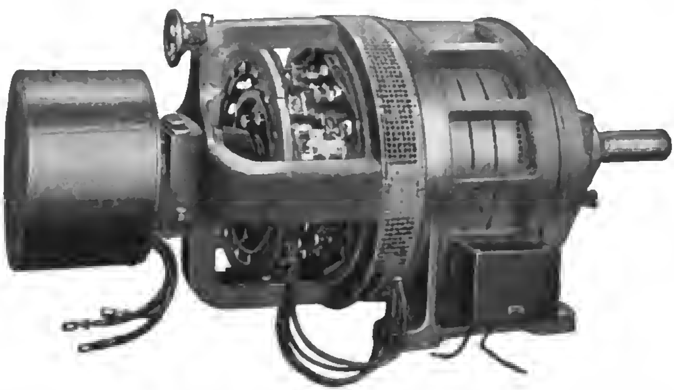


Fig. 18. General Electric Type BTA 3-Phase Adjustable Speed Motor with a Small Pilot Motor for Shifting the Brushes

The Century repulsion-induction machine is, strictly speaking, a repulsion-start induction-run motor as described earlier in this lesson. Fig. 19 shows a detailed cross-sectional view of this motor built in sizes from 1/8 to 40 horsepower for single-phase operation at 110- or 220-volt. The starting torque of this motor ranges from 2½ to 3½ times full load torque and will not exceed 3½ times full load current when directly connected to the line. The brushes ride the commutator only during the starting period, thus insuring long brush life and noiseless operation. As there is no sparking during operation, this motor causes radio interference only while starting. Its torque characteristics make it especially adaptable to operation of apparatus such as plunger pumps, compressors, oil burners, and refrigerating machines.

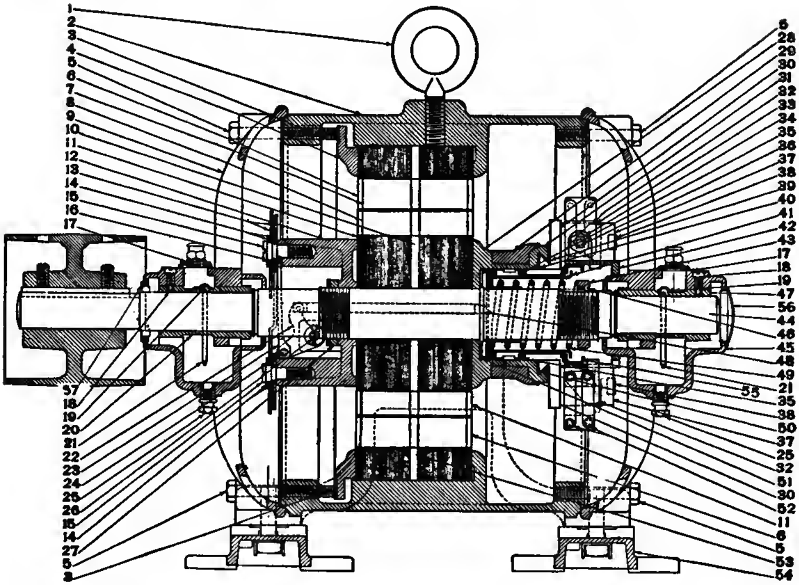


Fig. 19. Assembly View of a Century Repulsion-Start Induction-Run Motor

1. Eye Bolt.
2. Motor Frame.
3. Field Ring Locking Screws.
4. Field Ring.
5. Bearing Bracket Cap Screws.
6. Field Fibres.
7. Field Core.
8. Rotor Core.
9. Back Bearing Bracket.
10. Rotor Ventilating Grid.
11. Rotor Fibres.
12. Back Flange.
13. Governor Weights.
14. Governor Weight Stud Washers.
15. Governor Weight Studs.
16. Governor Weight Rivet.
17. Oil Well Covers.
18. Dog Point Bearing Screws.
19. Oil Ring Guards.
20. Back Bearing.
21. Oil Rings.
22. Bell Crank.
23. Governor Weight Link.
24. Governor Weight Link Rivet.
25. Oil Plugs.
26. Bell Crank Stud.
27. Back Flange Nut.
28. Front Flange.
29. Commutator Head.
30. Commutator Segments.
31. Commutator V. Ring
32. Parallel Motion Fingers.
33. Brush Holder Gib.
34. Gib Screw Lock Nut.
35. Short Circuiting Segments.
36. Gib Screw.
37. Carbon Brushes.
38. Brush Springs.
39. Paper Commutator Insulating Ring.
40. Mica Commutator Insulating Ring.
41. Spring Barrel.
42. Brush Holder.
43. Spring Barrel Nut.
44. Rotor Shaft.
45. Front Bearing Bracket.
46. Spring Bearing Nut Locking Screw or Spring.
47. Front Bearing.
48. Governor Weight Pins.
49. Governor Spring.
50. Paper Commutator Insulating Ring (Taper).
51. Governor Weight Pin Guide Washer.
52. Parallel Motion Links.
53. Field Ventilating Grid.
54. Subbase.
55. Spring Barrel Ring (Steel).

WAGNER REPULSION-INDUCTION MOTORS

The Wagner Electric Company makes a line of motors very closely paralleling the Century line. Their repulsion-start induction-run motors are made in sizes from 1/10 to 15 horsepower in all standard voltages and frequencies. The frame is of rolled steel and welded construction into which the wound stator core is inserted. The stator iron is high-grade annealed sheet made especially for the

work. Fig. 20 shows a section of the Wagner repulsion-start induction-run motor stator. Note the excellent coil fit in the slots and the maple wedges holding the coils firmly in place. These

Fig. 20. Arrangement of Winding the Pole Groups in the Stator
Courtesy of Wagner Electric Corporation

stators are thoroughly impregnated with insulating compound and baked twice, after which they are thoroughly sprayed with air-dry varnish to increase resistance to oil and moisture.

Fig. 21. Rotor of a Wagner Type RA, Repulsion-Start Induction-Run Motor

The rotor shown in Fig. 21 is treated and insulated in the same way as the stator. The slots are slightly skewed to reduce magnetic noise and to eliminate variation in starting torque at different rotor positions. The commutator is of the end type construction and is

short-circuited by a necklace of small copper segments forced against the commutator by a centrifugal switch. At the same instant this switch short-circuits the commutator, it lifts the brushes so that no contact is made while the motor is operating at normal speed.

Wagner also makes a straight repulsion-induction motor in capacities of 1 to 3 horsepower. The rotor, in addition to the wire winding like other armatures for repulsion motors, has a regular

Fig. 22. Wagner Type RG Single-Phase Induction Motor

squirrel cage winding. Some of the advantages claimed for this construction of winding are: a smooth speed torque curve, without fluctuations, which makes the motor adaptable for severe starting duty; low starting current; close speed regulation; positive operation on low voltage; excellent efficiency; high power factor; excellent commutation with resulting long brush and commutator life; and no internal short-circuiting mechanism. The brushes must be in contact with the commutator at all times. Fig. 22 shows an assembled view of this late development in repulsion-induction motors.

DELCO REPULSION-INDUCTION MOTORS

The Delco repulsion-induction motor is fundamentally the same as the Wagner and Century motors of this type. These motors have

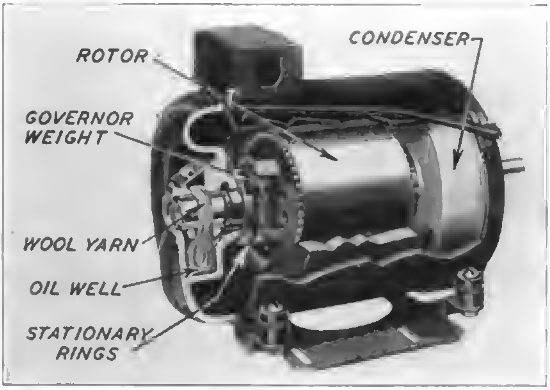


Fig. 23. A Capacitor Motor with Internal Condenser. The Starting Winding Is Connected to the Stationary Rings and as the Rotor Approaches Full Speed, the Governor Weight Moves Outward and Opens the Circuit

Courtesy of Howell Electric Motors Company

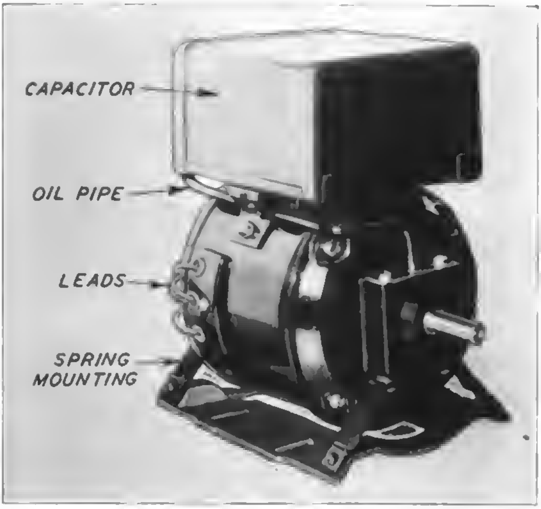


Fig. 24. Westinghouse Type FT Single-Phase Capacitor Motor. The Capacitor Unit Can Be Removed from the Motor and Mounted at any Convenient Location

the end type commutator on the rotor. The short-circuiting device throws against the outside of the commutator while running, which is somewhat different than other motors of this kind. These machines

are made in capacities from ⅙ to 1½ horsepower and used principally for refrigeration purposes. The following frequencies are available: 25, 30, 40, 42, 50 and 60 with voltages ranging as follows: 80-160, 100-200, 104-208, 105-210, 110-220, 120-240, 125-250, 150-300, 190-380, 220-440.

Capacitor Motor. The capacitor motor was first developed to provide a quiet operating fractional horsepower machine for driving oil burners, pumps, compressors, stokers, refrigerators, and similar equipment requiring high starting torque, long annual run, and high power factor and efficiency. Motors of this type are made with condensers mounted internally and externally. The external mounting is favored especially with smaller units. Capacitor motors are now available up to 10 horsepower, but the condenser unit increases the first cost very materially over repulsion-induction or squirrel cage machines. Figs. 23 and 24 show how condensers are mounted internally and externally with reference to the motor frame.

CLASSIFICATION OF FRACTIONAL HORSEPOWER MOTORS

The National Electric Manufacturers Association has set up the following classification of small motors according to what is called the annual service characteristics of the motors. The two classifications are *long annual service* and *short annual service.* The short annual period is less than 1000 hours per year, and the long annual period is considerably over 1000 hours per year. Motors with long annual service characteristics are intended for use in general purpose applications where the motor is expected to operate at frequent intervals and for long periods of time; where high efficiency and high power factor are desirable; where quiet operation is required; and where normal torque characteristics are needed. Oil burners and refrigerators for household use are very excellent cases. Motors with short annual characteristics are intended for those applications where the motor is expected to operate only at infrequent intervals and for short periods of time. Washing machines and ironers are typical examples of this type of service.

POLYPHASE MOTORS

How the torque is developed for a two-phase motor has already been shown in the explanation of the operation of a single-phase

motor. The only difference between a two-phase winding and a split-phase winding is that the two-phase winding is energized from separate phases of a two-phase circuit while the split-phase is arranged through inductance or capacity to accomplish the necessary current displacement in the two windings. The currents must be out of phase with each other in the two circuits in order to set up torque through the revolving stator field. The two-phase alternator windings are arranged to do this while the single-phase circuit must resort to artificial means to meet the requirements necessary to set up a revolving stator field. The two-phase circuit is far superior to the single-phase for providing starting torque for motors. The three-phase revolving field provided from the three-phase circuit has many advantages over the two-phase system. Installation costs are less; motors have better starting characteristics; power factor and speed regulation is better; and efficiency is higher with the three-phase system.

Where the single-phase motor has one revolving magnetic field set up by the stator, the two-phase circuit provides two fields 90 degrees apart, and the three-phase has three fields each 120 degrees apart. This phase relationship is maintained in the motor stator as well as in the generator windings which makes possible the effective use of the magnetic poles provided by these currents. In a non-inductive circuit, the current curves would have exactly the same phase relationship as the voltage curves, but of course with different values. The introduction of a motor in the three-phase circuit would have practically the same phase displacement effect on the current and voltage in each phase, hence the 120 degree-phase relationship of the currents in each phase would be maintained even though the power factor was poor. How the three-phase winding, with its rotating magnetic field, polarizes the stator through the induced currents is shown in Fig. 25.

The stator winding is placed around the stator with the various phases 60 degrees apart. Reversing the connections to one group of coils sets up the 120 degree-phase relationship which always exists in the three-phase circuit. The current curves for the separate phases are shown in the lower part of Fig. 25. Coils of the stator windings are indicated as *A, B,* and *C*. At the first position selected on the sine waves, note that the current in phase *A* is at a maximum

value positively, and the currents in phases *B* and *C* are both negative, but the current in phase *B* is approaching zero while the current in phase *C* is increasing in the negative direction. The induction from these phases causes poles on the rotor indicated by the arrows. Note that the arrows in rotor No. **1** are opposite phase *A* for the first

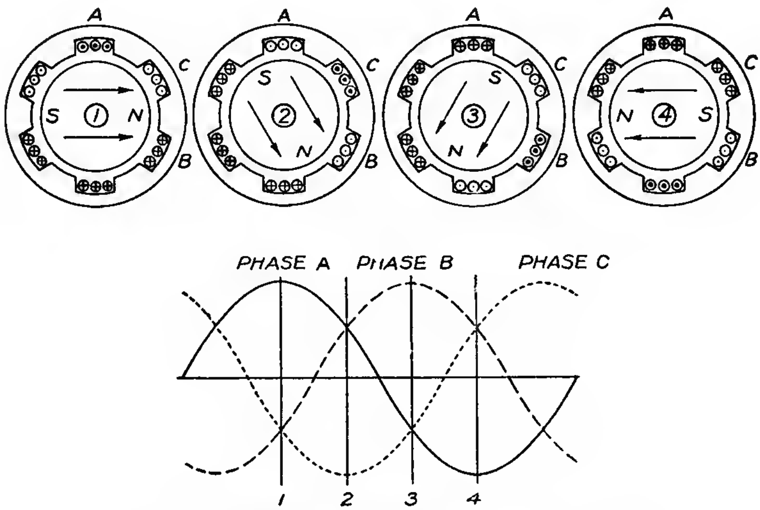


Fig. 25. Rotor Positions During Different Parts of One Cycle

position on the sine curves. Note how these arrows rotate for each of the four instantaneous valves of current as shown by the four rotor positions.

The instantaneous valves of current are taken just 60 degrees apart, which makes the 1st and 4th positions 180 degrees apart. This is a 2-pole winding and the rotor has made just one-half turn from position 1 to position 4. If this stator had been wound with four poles instead of two, the same change on the sine wave would have rotated the rotor only one-fourth of a turn, and a 6-pole one-sixth of a revolution, etc. For this reason rotors used in the stator fields with a large number of poles have slow speeds.

Squirrel Cage Motor. The squirrel cage motor is the most common type of alternating-current motor. It is used in single-phase induction motors, two-phase, and three-phase machines. Properly constructed, it is the least troublesome of any moving element made for motors. The simplest and most common type of

squirrel cage is made by assembling a series of copper rods in the slots of the iron rotor case and welding the ends to a copper ring. If viewed with only the copper assembly, it looks like the old-fashioned squirrel cage from which it got its name. The single-phase motor has been already discussed in this lesson, and the two-phase is becoming scarce; therefore, only the three-phase motor will be illustrated and referred to in the remainder of this work. Fig. 26 shows two standard types of rotors. *A* shows an assembled welded copper bar and *B* shows the cast aluminum type.

Fig 26*A*. Squirrel Cage Rotor as It Would Appear When Removed from the Slots of the Laminated Sheet Steel Rotor Core and Reassembled

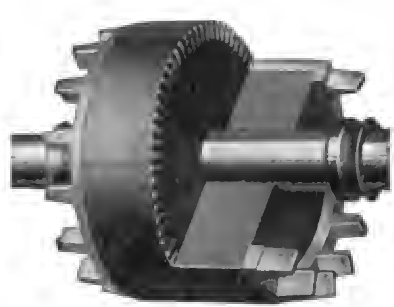


Fig. 26*B*. Section of Finished Cast-Aluminum Rotor. The Molton Aluminum Is Cast in Slots in the Laminated Sheet Steel Core

Courtesy of General Electric Company

The squirrel cage polyphase induction motor is built in any size needed from 1/8 to 5000 horsepower. Voltages are standardized at 110-220-440-550 and 2200 volts and built for frequencies of 25-, 40-, and 60-cycles. Sleeve bearings, ball bearings, and roller bearings may be obtained if desired, although the roller bearings are not standard with all makes of motors. All types of frames, open, semi-enclosed, enclosed, drip-proof, splash-proof, and explosion-proof, are available wherever the application requires. All manufacturers make motors with 40° C. rating and some add a line of 50° C. motors. A 40° C. motor has a 20 per cent greater overload capacity than a 50° C. motor. A great deal of care is taken in the design of all motors to provide proper ventilation for cooling not only the windings but the iron as well. A current of air directed over and through the machine is usually the method employed to dissipate heat losses. Sometimes additional circulating apparatus is used, but ordinarily

fans on the motor are used for this purpose. Fig. 27 shows a cross-sectional view of a motor with arrows indicating the direction of air used for ventilation.

Up until a few years ago, a squirrel cage motor was the only motor in the constant speed alternating-current field. At the present time all alternating-current motor manufacturers are making at least three and some as many as seven types of squirrel cage induction motors.

The three more common types of squirrel cage motors are grouped as follows: First, the normal torque normal-starting-current

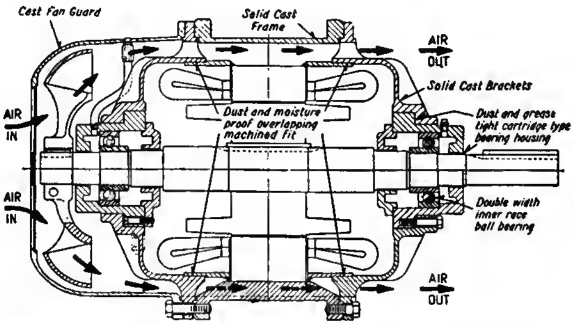


Fig. 27. Cross Section of a Fan-Cooled Fully Enclosed Squirrel Cage Motor

motor. This motor has the highest efficiencies and power factors of all standard lines of induction motors and is more widely used than any of the others. Some type of starting device is usually required to reduce line disturbance when starting. The second group includes the normal torque, a low-starting-current motor designed to do the work of the ordinary motor but start with less starting current. Smaller and more compact control may be employed with this motor. The third group of motors of this type is high-torque, low-starting-current. These motors have a higher percentage of starting torque than either of the other groups, with a starting current no greater than the second group uses. This motor has high full speed efficiency and power factor and is recommended for driving compressors, conveyors, and other loads requiring high starting torque. Fig. 28 shows the rotor construction which will provide the third group of motors with desired operating characteristics. Note the double squirrel cage and large deep slots provided for the low resistance part of cage.

In Fig. 29 the comparative table gives a picture of the conditions developed in various types of squirrel cage rotors by changing the shape of the slots and the winding used. The starting torque, starting current, slip, power factor, and efficiency are the essential factors in analyzing the behavior of a motor. Knowing the motor characteristics is only part of a job of selecting the proper machine to apply to the work. All the operating conditions such as

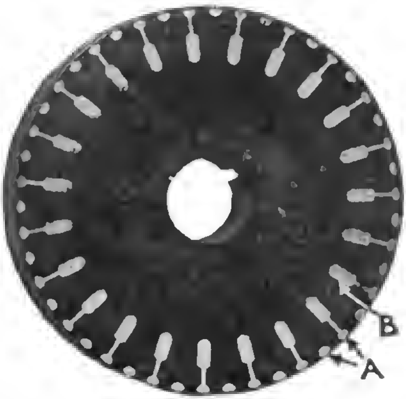


Fig. 28. Double Squirrel Cage Rotor Windings. A—High-Resistance, Low-Reactance Winding Which Give High Starting Torque with Low Starting Current. B—Low Resistance Winding to Improve Efficiency and Speed Regulations at Full Load
Courtesy of General Electric Company

starting, running, power company requirements, voltage, hazards such as explosive dust, flying particles, water and explosive gases must be given consideration before definite decision is made in picking a motor for a job.

The interior view of a squirrel cage induction motor, Fig. 30, gives a very clear picture of the construction, assembly, ventilation, and lubrication features of this type of machine. The frame is welded steel, and stator and rotor cores are made from special laminated steel. The coils are well protected, and the shaft is provided with a circulating fan which directs a current of air over the windings and the rotor and stator steel. All parts are interchangeable for a given size and can be easily and quickly changed whenever necessary. There is nothing to get out of order except possibly bearings and insulation which with proper care rarely happens.

Wound Rotor Induction Motor. The squirrel cage induction

motor provides very little change in speed; only a very limited variation may be made by raising or lowering the terminal voltage. In

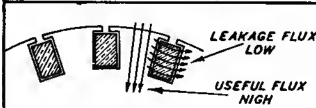
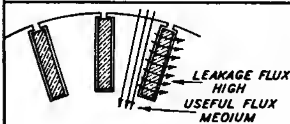
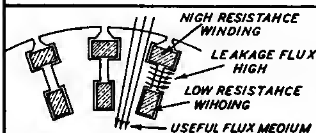
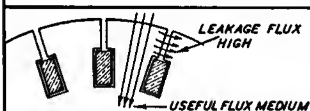
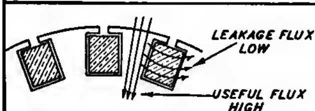
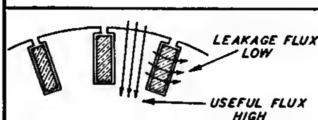
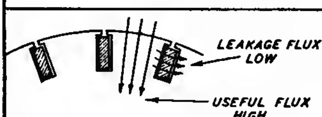
ROTOR AHO SLOT CONSTRUCTIOH	STARTING TORQUE	STARTING CURRENT	SLIP	POWER FACTOR	EFFICIENCY
	NORMAL	NORMAL	LOW	HIGN	VERY HIGN
	NORMAL	LOW	LOW	FAIRLY HIGH	LOW
	HIGH	LOW	MOOERATE	LOW	GOOO
	LOW	LOW	VERY LOW	HIGH	HIGH
	LOW	NORMAL	LOW	HIGH	HIGH
	HIGH	FAIRLY HIGH	FAIRLY HIGN	FAIRLY HIGH	FAIRLY NIGH
	VERY HIGH	VERY HIGH	VERY HIGH	FAIRLY HIGN	FAIR

Fig. 29. Different Kinds of Slot and Rotor Construction and the Results Obtained from Them

order to provide a motor for polyphase circuits with practically unlimited speed variation from no load to full load, the wound rotor slip-ring motor was developed. The torque developed by this motor is practically proportional to stator current. This makes the line cur-

rent the lowest for starting of any induction motor. The efficiency is also good at slow speeds, but power factor is low for this machine. The stator construction is standard, as in other types of polyphase motors, but the rotor has a low resistance winding which is connected in phases to three slip rings. The control is obtained through the use of a contactor and resistance bank connected to the rings.

Fig. 30. A Squirrel Cage Three-Phase Motor with Bearing Bracket Removed
Courtesy of Lincoln Electric Company

Slow speeds are developed when high resistance is introduced into the rotor circuit which increases as the resistance is decreased.

Slip-ring motors are available in all sizes from ¼ to 5000 horsepower for all standard voltages. Through the control they are made reversible speed. They are used on cranes, hoists, and metal rolling mills where reversing duty is essential and where frequent stops and starts are encountered. Because this motor may be "plugged," that is reversed from one direction to the other with power directly from the line, these motors require extra heavy shaft and rotor construction to withstand this abuse. Fig. 31 shows a large heavy-duty wound rotor motor for steel mill service. Fig. 32 shows a partly wound rotor.

Multispeed Motor. The other method of obtaining an alternating-current adjustable speed motor is to use a squirrel cage

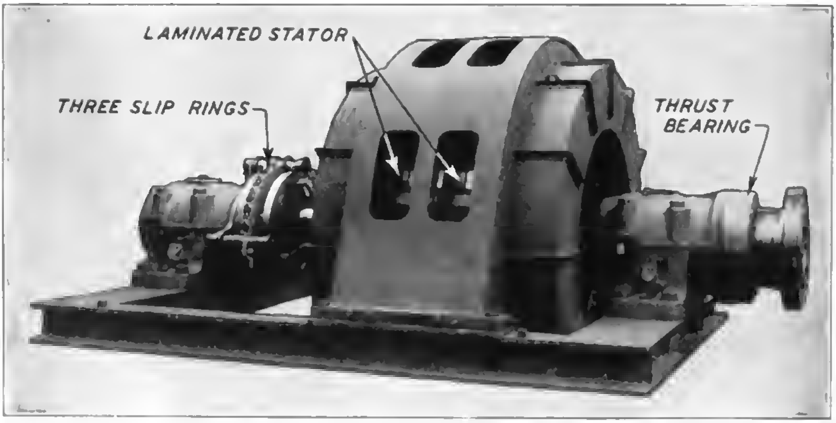


Fig. 31. A Westinghouse Type CW Heavy-Duty Wound-Rotor Induction Motor

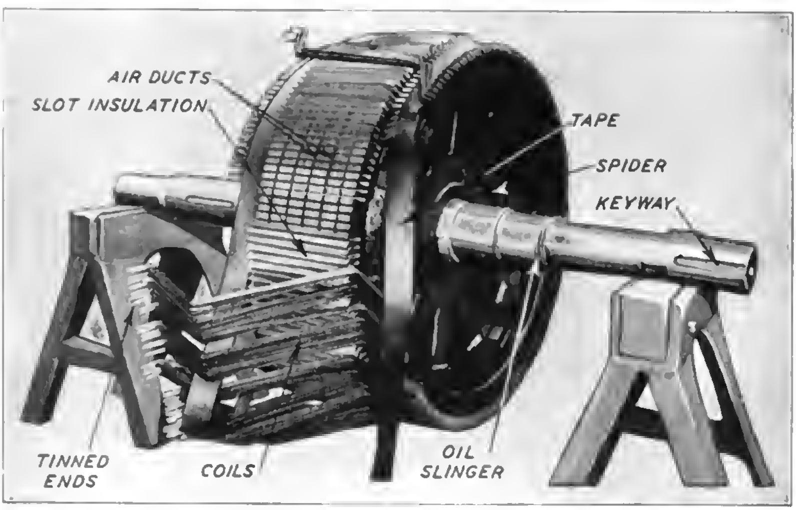


Fig. 32. A Partially Wound-Rotor
Courtesy of Westinghouse Electric Company

rotor and wind the stator a large number of stator poles. The leads from these coils are brought out to a pole changing switch. In this way as many as two, three, or four definite speeds may be obtained. For example, a 60-cycle three-phase motor may be made to run at

1800, 1200, 900, and 600 r.p.m. Fig. 33 shows a multispeed motor installation with controlled apparatus.

Synchronous Motor. Synchronous motors, like alternating-current generators, are usually built with stationary winding and revolving field which must be excited from some source of direct current. Any alternator can be made to operate as a synchronous

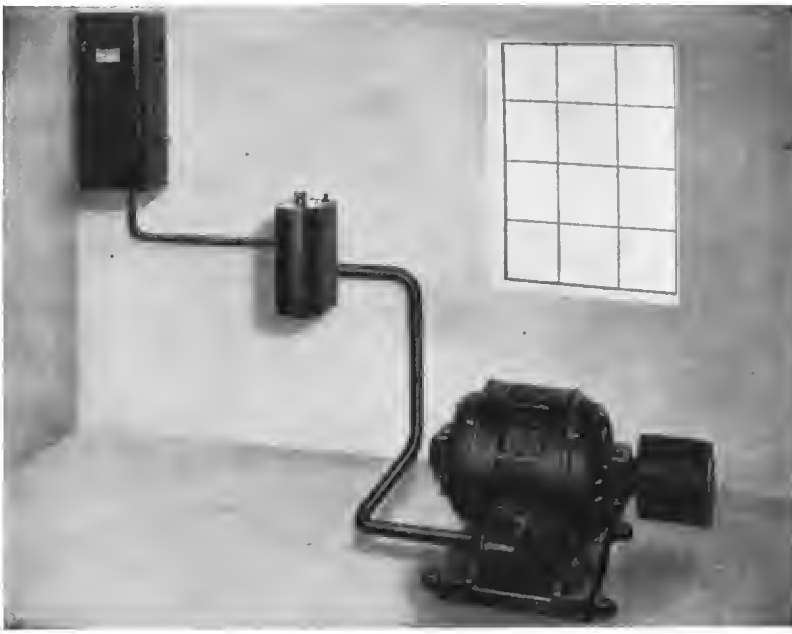


Fig. 33. A Multispeed Induction Motor Controlled by a Drum-Type Pole-Changing Switch
Courtesy of General Electric Company

motor, but trouble due to hunting effects may develop objectionable power surges on the transmission system. All synchronous motors develop this tendency to oscillate depending upon the tortional conditions of the load being driven. To overcome this trouble, a damper winding is placed in slots in the pole faces. This short-circuited winding very effectively eliminates hunting troubles.

The synchronous motor has proved itself more efficient, operates at higher power factor, has absolutely constant speed regulation, and competes very favorably in first cost with other induction motors. It is ideally suited for a constant load where speed must be maintained uniform under all conditions. By field control the synchro-

nous motor can be made to improve the power factor of a plant or power line and thereby reduce the cost of power, especially where the contract with the power company carries a penalty clause for low power factor.

These motors are built in capacities ranging from 20 to 9000

Fig. 34. A 600 Horsepower, Synchronous Motor Having 52 Poles and Operating at a Speed of 138 r.p.m.
Courtesy of Electric Machinery Manufacturing Company

horsepower at speeds varying from 1800 to 60 r.p.m. All standard voltage and frequencies are met in these motors. Synchronous motors are used to drive compressors, paper mills, pumps, blowers, rubber mills, cement mills, mines, steel mills, flour mills, motor generator sets, and oil refining machinery. Fig. 34 shows a large synchronous motor operating a flour mill. The stator frames for practically all these large machines are fabricated from steel plate and welded in the same manner as alternators are constructed.

In the past, the chief objection to the synchronous motor was its lack of starting torque. This has been overcome in various ways. The General Electric Company makes what is called the super synchronous motor, Fig. 35, so arranged that the stator is free to rotate as well as the rotor. In starting, the stator is brought up to synchronous speed and a brake is then applied which gradually slows up the revolving stator as the field is increased in speed.

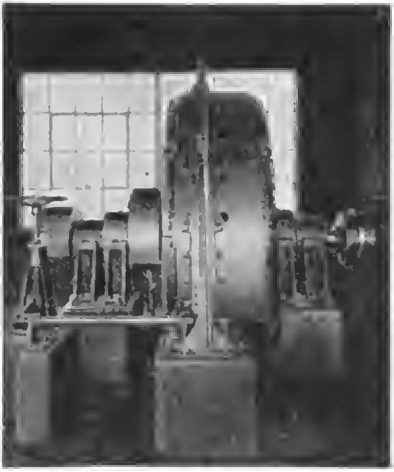


Fig. 35. A General Electric 400 Horse-power Type TSR Synchronous Motor. Stator Is Supported on Inner Set of Bearings and Rotor on Outer Set of Bearings

Other companies, by special rotor design with heavy squirrel cage windings in the poles, are now able to successfully build synchronous motors with satisfactory starting torque.

Fynn-Weichsel Motor. The Fynn-Weichsel motor, Fig. 36, developed by the Wagner Electric Co., is a combination of the slip-ring and direct-current motor. The stator has two windings displaced by 90 degrees. One of these windings is connected through an adjustable resistance to the direct-current brushes and the other stator coil is short-circuited with another adjustable resistance. The rotor of this motor, Fig. 37, has two independent sets of windings consisting of a direct-current set of coils connected to a direct-current commutator and a three-phase winding connected to slip rings. Three-phase power is supplied to the slip rings which is the only connection this motor has to the power lines.

In starting, this machine has the characteristics of a slip-ring induction motor. As soon as the machine reaches full speed, the direct current automatically supplied to the stator field from the commutator makes it a synchronous motor. The brushes in field

Fig. 36. Exterior View of Fynn-Weichsel Motor with Hinged Cover over Commutator
Courtesy of Wagner Electric Corporation

circuits are set so as to give the motor proper starting torque to meet the needs of the load. This motor has the advantage over the ordinary synchronous motor, being able to operate as an induction

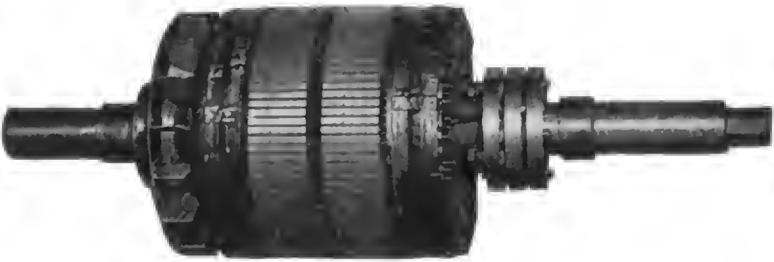


Fig. 37. Rotor of Fynn-Weichsel Motor
Courtesy of Wagner Electric Corporation

motor on heavy overloads, and immediately pull into synchronism as soon as the load becomes normal again. The Fynn-Weichsel motor can be adjusted to have power factor corrective effects on the line by changing the resistance in the direct-current circuit to the stator.

ARMATURE WINDING

TYPES OF ARMATURES

Ring Armatures. Ring armatures were first used by Pacinotti in 1860, who wound the wire between projecting teeth upon an iron ring, Fig. 21. In ring windings the parts of the windings which pass through the inside of the ring do not cut any magnetic lines (assuming there is no magnetic flux passing across the opening inside of the iron ring), and, as a result, are inoperative, so far as the e.m.f. of the machine is concerned.

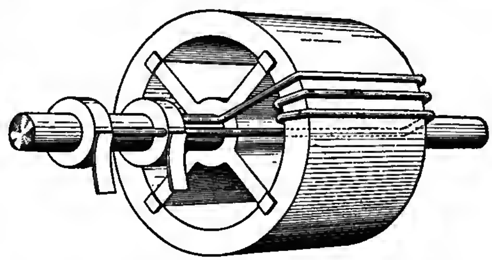


Fig. 21. Partially Completed Ring-Wound Armature

A core of the Gramme ring type is shown in Fig. 22, and a complete Gramme ring armature provided with a commutator of usual form is shown in Fig. 23.

Drum Armatures. The principle of the drum winding is shown in Fig. 24, and it is apparent that it is much simpler than the ring winding. Each wire is placed on the outside of the drum, usually parallel to the axis of the armature core, and is connected to another wire by means of connecting wires called end-connections, which do not pass through the core. The only reason for having any opening in the core at all, other than to save the material, is to improve the ventilation and cooling of the armature. In two-pole machines

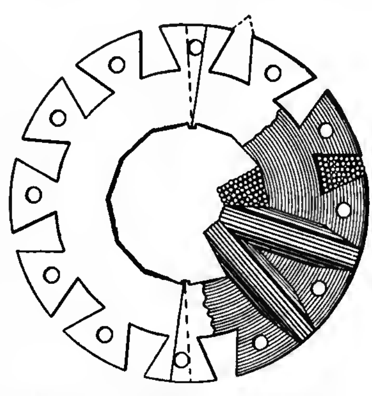


Fig. 22. Simple Gramme Ring Winding

the end-connections run across the ends of the core and connect wires which are almost diametrically opposite. In multipolar machines the end-connections join wires which are separated by a

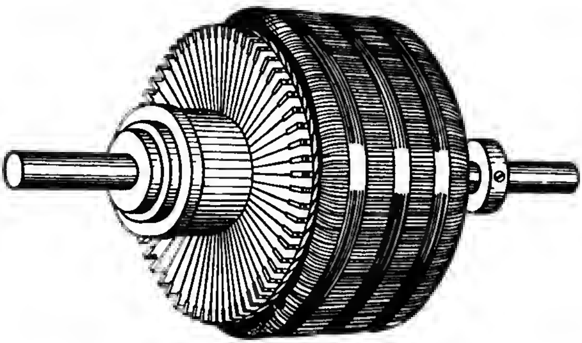


Fig. 23. Couple Gramme Ring Winding

distance approximately equal to the distance between corresponding points on adjacent poles, so that the electrical pressures in the wires thus connected will act in the same direction around the loop.

The drum armature may be thought of as derived from the ring armature by moving the inner connections of the winding, or the

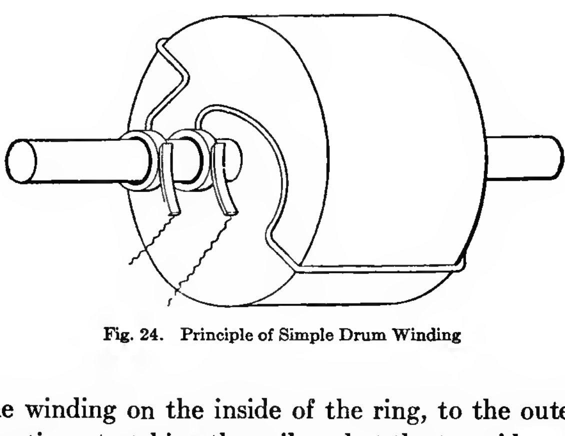


Fig. 24. Principle of Simple Drum Winding

part of the winding on the inside of the ring, to the outer surface, at the same time stretching the coil so that the two sides will occupy approximately corresponding positions under adjacent poles.

Disc Armatures. The disc armature differs from the other two in that the wires in which the electrical pressure is induced, instead

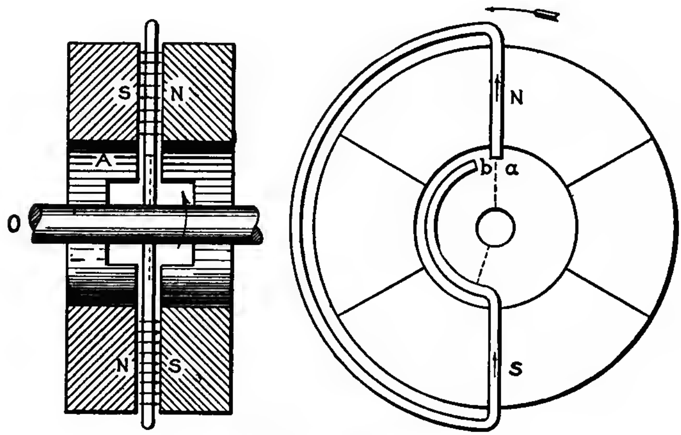


Fig. 25. Principle of Disc Armature

of being on the outer cylindrical surface of the armature core, are placed radially on the flat sides of a disc. The principle of the disc is shown in Fig. 25.

ARMATURE CONSTRUCTION

Purpose of Armature Core. The function of the armature core is twofold: it supports the armature winding and it carries the flux from one pole core to the adjacent pole cores; that is, it completes the magnetic circuit between the pole pieces. On account of its high permeability and great strength, iron is by far the best material for armature cores. It has become the practice to build up armature cores of thin, soft iron or mild steel discs, insulated from one another by varnish, rust, or paper. An armature core composed of such sheets, forced together by hydraulic or screw pressure, is found to be from 85 to 95 per cent iron, the remainder of its volume being made up of insulation, air space, etc.

Core Bodies. The cores of armatures are made of laminae (thin discs) of wrought iron or mild steel. These discs are stamped out of sheet metal, and range from 0.014 inch to 0.025

inch in thickness, the former thickness being that most often used at the present time. Core discs up to about 30 inches in diameter are punched in one piece, while larger diameters are

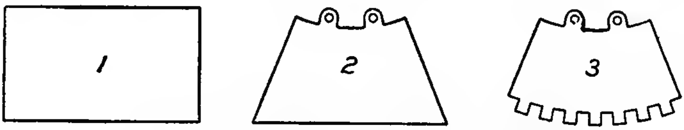


Fig. 26. Order of Stamping Armature Core Segments

stamped out in sections, Fig. 26, and the core built up as indicated in Fig. 27, alternating the joints. These stampings are now so accurately made that, after assembling the discs into a core, the slots need not be milled out, as was formerly necessary.

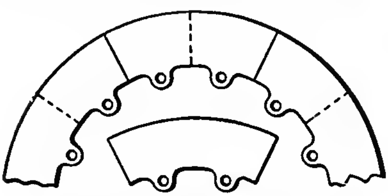


Fig. 27. Method of Building up Armature Core from Segments

Milling is most objectionable because it burrs over the edges of the discs. The burrs thus produced connect adjacent discs and facilitate the flow of eddy currents, thereby defeating the purpose of lamination. Turning after assembling also tends to increase the iron losses. Hence, if it is found that the periphery of the core body is irregular, it should be ground true.

The core discs are insulated from each other either by a thin coating of iron oxide on the discs or by a thin coating of japan varnish. Sometimes shellac or paper is used for insulating these laminae; but on account of the greater expense and the fact that the efficiency is only slightly bettered, these latter are applied only in special cases.

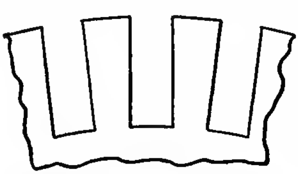


Fig. 28. Armature Teeth with Parallel Slots

Shapes of Armature Teeth. The armature cores used in practice are almost always provided with a toothed surface. Thus the armature winding is protected, the length of the air gap reduced, and the winding is prevented from slipping in the core. The general efficiency of the machine is greater than when a smooth core is used. The number of teeth must be relatively

large, about four per inch of armature diameter, to prevent noise and excessive eddy-current losses in the pole faces. A common form of armature tooth is slightly narrower at the root than at

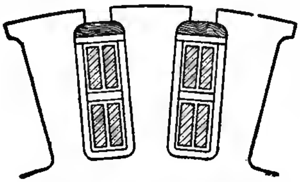


Fig. 29. Teeth with Projecting Tops

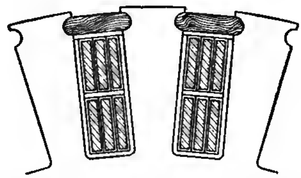
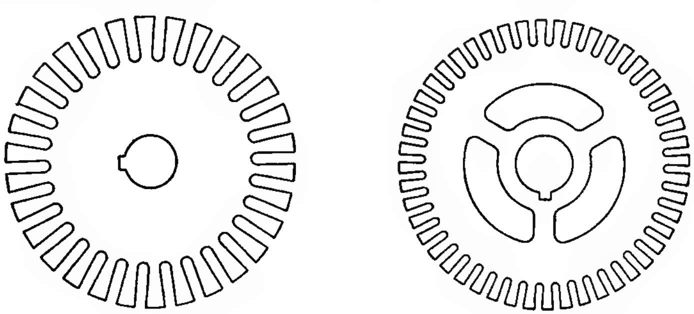


Fig. 30. Notched Teeth to Hold a Wedge

the top, the resulting slot having parallel sides, Fig. 28. Fig. 29 illustrates a form in which the tops are slightly extended to give a larger magnetic area at the top, thus decreasing the reluctance of the air gap and helping to retain the inductors in the slots by the insertion of a wedge of wood. The latter object is also attained by notching the teeth as in Fig. 30, in case it is not desirable to increase the area of the top of the tooth.

Binding-Wire Channels. In machines using binding wires to hold the armature inductors in the slots, it is usual to stamp some of the core discs of slightly reduced diameter so that the binding wires may be flush with the surface of the armature. The reduction is seldom more than $\frac{1}{4}$ inch on the diameter, giving a channel not more than $\frac{1}{8}$ inch deep. The width is determined by the number and the size of the binding wires.



Figs. 31 and 32. Forms of Armature Core Discs for Small Machines

Mounting of Core Discs. Some mechanical means must be provided to hold the core discs together, and to connect them rigidly to the shaft. In the case of small cores not exceeding

15 inches in diameter, the core discs take either of the forms shown in Figs. 31 and 32, the latter being preferable on account of increased ventilation. The laminae are simply keyed to the shaft, being held together under heavy pressure by end-plates of cast steel or cast iron, which are in turn pressed inward either by nuts fitting in threads upon the shaft or by bolts passing through, but insulated from the armature discs and end-plates.

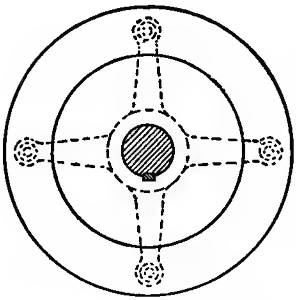


Fig. 33. Core Discs Bolted to Spider—Bolts Pass through Discs

Large cores in which the discs are made in sections, or for which the material of the core near the shaft is not required, are built upon an auxiliary support called a spider, which has different forms, depending on the mode of attachment between it and the core discs. Fig. 33 shows the discs held together and to a skeleton pulley, or spider, by bolts passing through them, the spider being keyed to the shaft. The objection to this construction is that the bolt-holes reduce the effective area of the core, thus strangling the magnetic flux. This difficulty may be overcome by placing the bolts internal to the core, as in Fig. 34, in which case they need not be so well insulated. Another and newer arrangement provides the discs with dovetail notches or extensions which fit into extensions or notches on the spider arms, Fig. 35. The sectional view shows the method of holding the laminae together by means of bolts and end-plates, also the *R* extensions for supporting the end-connections of a barrel winding.

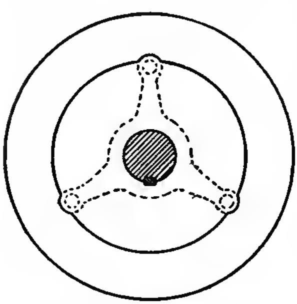


Fig. 34. Core Discs Bolted to Spider—Bolts Placed Inside of Discs

The hubs of armature spiders are usually cleared out between their front and back bearing surfaces to facilitate fitting the shaft; and in larger sizes the seating on the shaft is often turned to two different sizes to admit of easier erecting, Fig. 36. Figs. 37 and 38 show a spider and other features of construction of a

large machine. The rim of the spider is cut in six pieces, each of which has four dovetail notches. If it is cast in one piece, trouble may arise from unequal strains in the metal due to contraction.

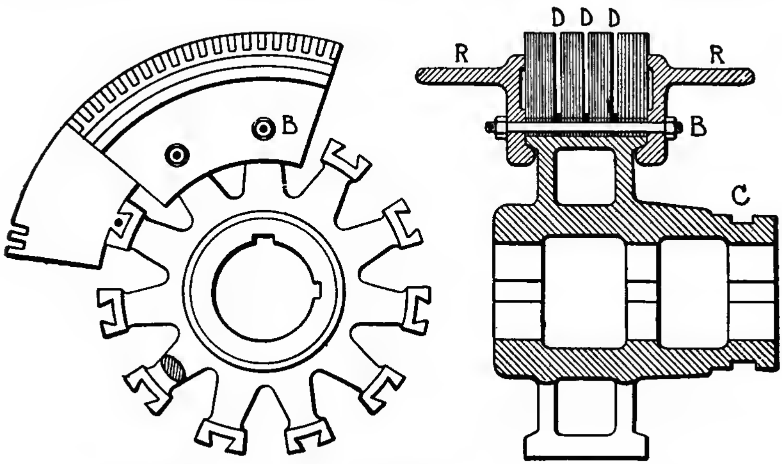


Fig. 35. Method of Mounting Large Armature Core on Armature Spider

Ventilating apertures are provided, and on the side of each arm, Fig. 37, are seen the seatings and bolt-holes for attaching the commutator hub and the rim which supports the winding. In Fig. 38, which shows a completed core, the supporting rim and narrow ventilating ducts are visible. Figs. 39 and 40 show two views of a completely assembled armature core and commutator ready for the winding; the armature spider is shown in Fig. 41. An armature core (in the process of construction) for a revolving armature is shown in Fig. 42; and a core (also in the process of construction) for a stationary armature, as used in alternating-current machines, is shown in Fig. 43.

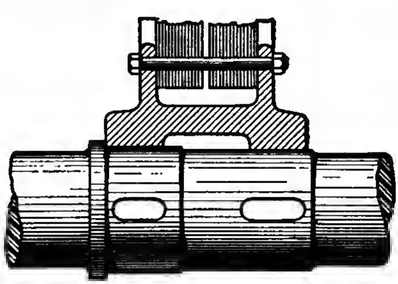


Fig. 36. Construction of Armature Hub

A completed armature core for a small machine is shown in Fig. 44.

Ventilating Ducts. Armature cores heat from three causes, namely, hysteresis, eddy-currents in the iron, and I^2R losses in

the copper inductors. In order that the temperature-rise of the armature shall not exceed a safe figure (60° C.), it is necessary in the large and heavy-duty types to resort to means of ventilation, usually ducts which lead the air out between the core discs. To keep the core discs apart at these ducts, it is necessary to introduce distance pieces, or ventilators. Fig. 45 illustrates some of these devices. At *A* are shown simple pieces of brass riveted radially at intervals to a special core disc 0.04 to 0.05 inch thick.

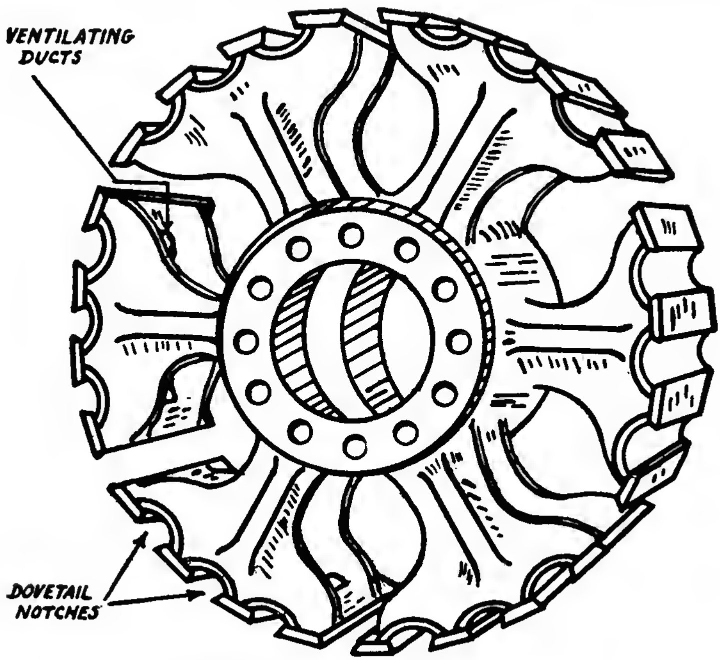


Fig. 37. Armature Spider for Large Generator

This form fails to provide adequate support for the teeth, a difficulty obviated in the form shown at *B*, which has, behind each tooth, a strip of brass about 0.4 inch wide set edgewise. This strip is cast with or brazed to a special casting of brass riveted to a stout core disc. In a recent construction, shown in Fig. 46, the core plate next to the duct is ribbed, affording good support for both the core and teeth of the next plate.

Binding Wires. With toothed-core armatures the inductors may be held in the slots by wedges of wood, as already stated, or

by bands of wire wound around the armature. These binding wires must be strong enough to resist the centrifugal force which tends to throw the armature inductors out of the slots, and yet must occupy as little radial space as possible, in order not to interfere with the clearance between the armature and the pole pieces. The common practice is to employ a tinned wire of hard-drawn brass, phosphor bronze, or steel, which, after the winding, can be sweated together by solder into one continuous band.

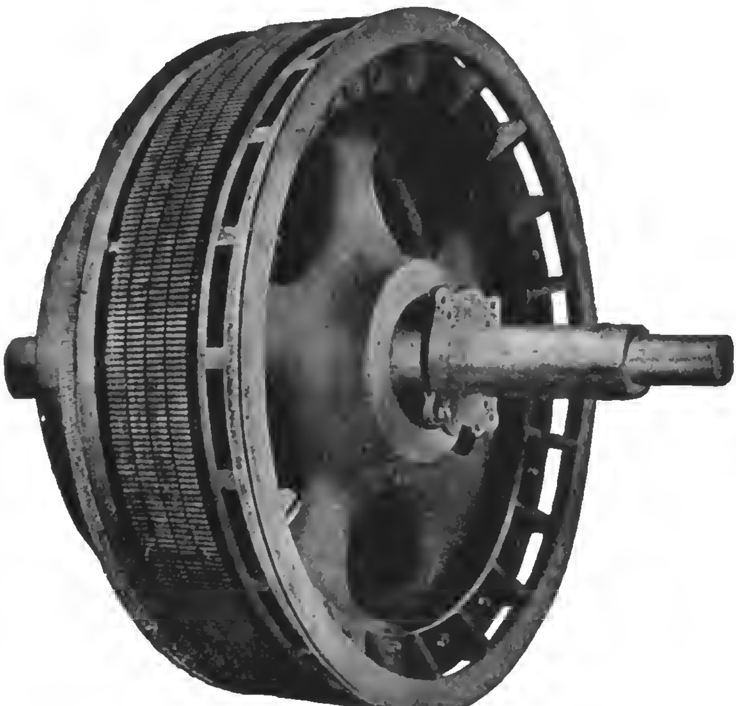


Fig. 38. Armature Core and Commutator Mounted on Temporary Shaft

Under each belt of binding wire a band of insulation is laid, usually consisting of two layers: first, a thin strip of vulcanized fiber or of hard red varnished paper slightly wider than the belt of wire, and then a strip of mica in short pieces of about equal width. Sometimes a small strip of thin brass, with tags which can be turned over and soldered down, is laid under each belt of binding wire to prevent the ends of the binding wires from flying out.

Wedges. At the present time, it is the customary practice to use either a partially closed slot, Fig. 29, or the open slot, Fig. 30, on all modern machines. With the open slot, a notch is cut in the side of the slot in order to hold the wedge, which can be inserted after the armature coils are in position in the slots.

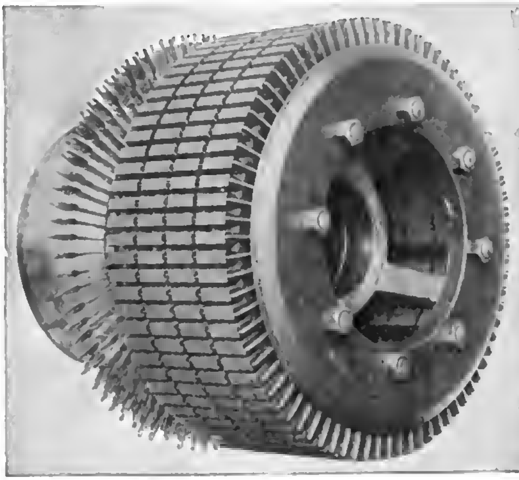


Fig. 39. Completely Assembled Armature and Commutator Ready for Winding (Rear View)
Courtesy of General Electric Company

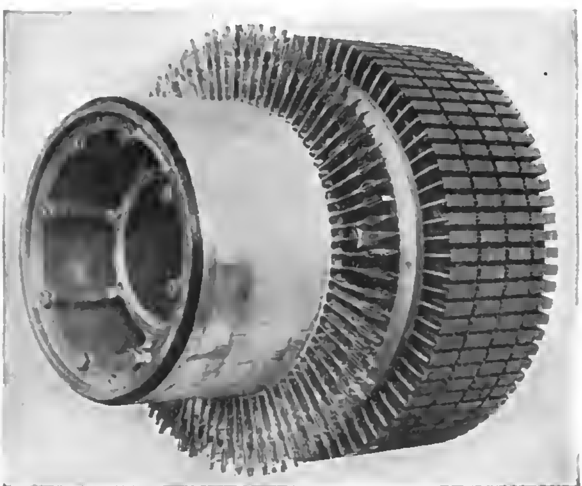


Fig. 40. Completely Assembled Armature Core and Commutator Ready for Winding (Front View)
Courtesy of General Electric Company

In the small armatures of fractional horsepower motors, the wedges are made from vulcanized fiber about $\frac{3}{16}$ to $\frac{1}{8}$ inch in thickness. These wedges are driven into the notches in the side of the teeth from one end of the core, Fig. 44. In this illustration, the operator is not driving a wedge in a slot but is fastening or driving

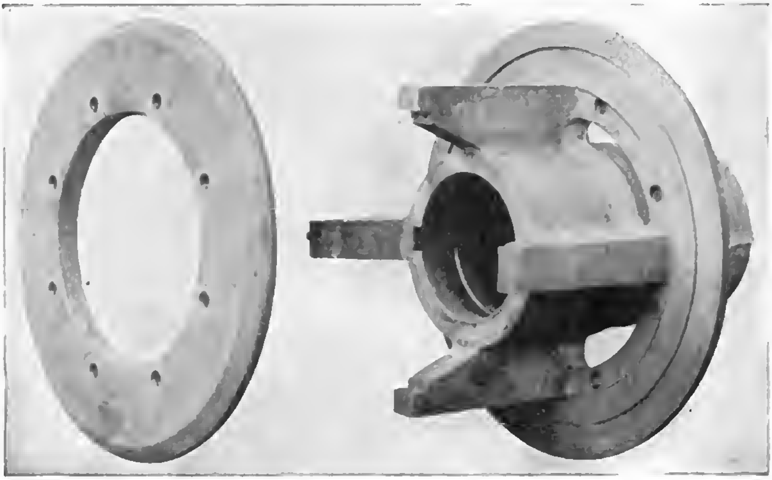


Fig. 41. Armature Spider for Armature Shown in Figs. 39 and 40
Courtesy of General Electric Company

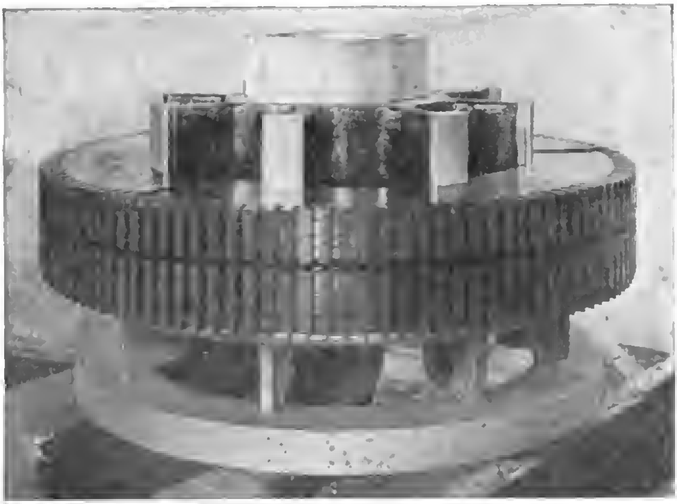


Fig. 42. Armature Core for Revolving Armature in Process of Construction
Courtesy of Allis-Chalmers Company

a steel key in the armature core spider in order to fasten the end plate to the armature spider.

The wedges used to hold armature coils in slots are also made of well baked hardwood, such as maple, and are shaped to fit the spaces provided for them as shown in Figs. 29 and 30. In some

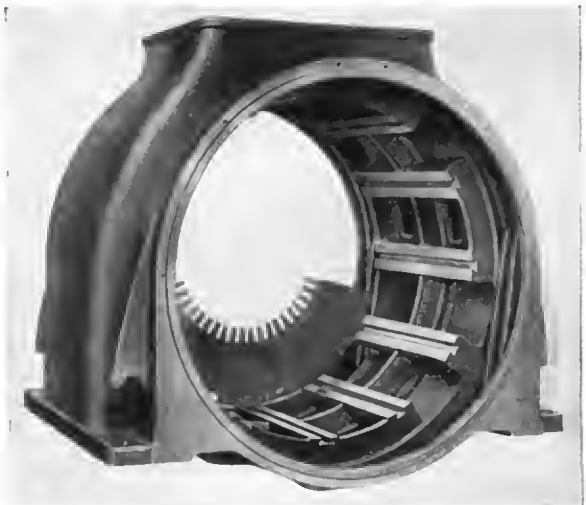


Fig. 43. Armature Core for Stationary Armature in Process of Construction
Courtesy of Allis-Chalmers Company

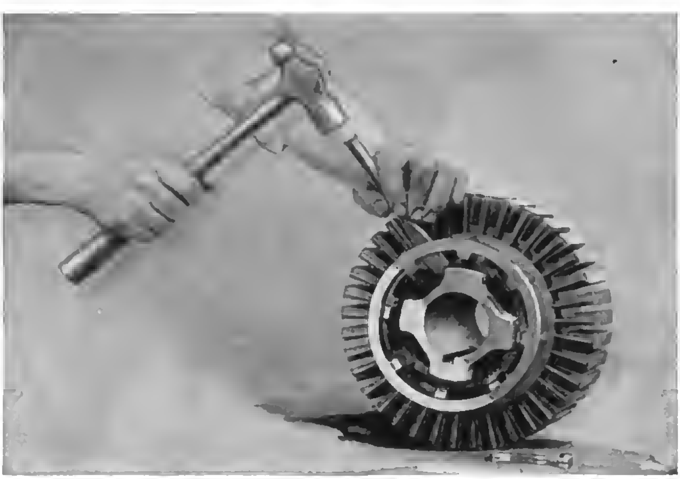


Fig. 44. Complete Armature Core for Small Direct-Current Machine
Courtesy of Reliance Electric and Engineering Company

cases, specially prepared wedges are used, being treated with bakelite and other substances to give them greater mechanical strength and insulating properties than wood or fiber.

In the armatures of the machines at speeds of 1200 revolutions per minute and less, and in the smaller sizes when the weight of the conductors in the slots is not excessive, these wedges are used to withstand the action of centrifugal force and hold the coils firmly in the slots. In the larger size armatures and in those of greater diameter or operating at higher speed than 1200 revolutions per minute, it is also necessary to use band wires around the core and on top of wedges in order to hold the coils in the slots.

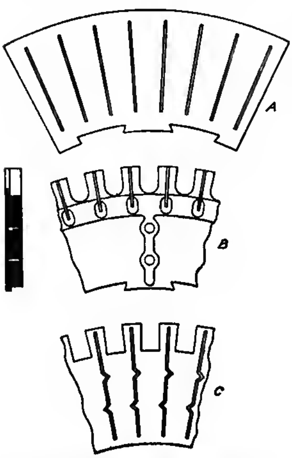


Fig. 45. Different Types of Distance Pieces of Ventilators

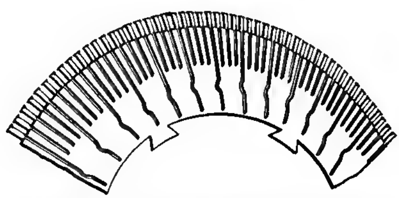


Fig. 46. Ribbed Core Plate Used in Forming Ventilating Ducts

COMMUTATOR AND BRUSH CONSTRUCTION

Commutator Bars. Commutator bars are almost always made of copper; other metals, such as brass, iron, or steel, are not satisfactory on account of pitting and burning. Rolled copper is preferable, because of its toughness and uniform texture; but in some cases, on account of the shapes necessitated by different methods of connection to the armature conductors and various clamping devices, the segments are either cast or drop-forged, the latter being at present the commercial type.

In order to secure a good fit, the cross-section of the bars should be properly tapered according to the number of segments that makes up the whole circumference. It is obvious that if the number of segments equals 360, each segment plus its insulation (on one side) should have a taper of 1 degree; while if the number

TABLE I

Thickness of Commutator Insulation

Voltage of Machine	Thickness of Mica	
	Between Neighboring Segments	Between Segments and Shell and between Segments and Clamping Device
Less than 150	0.020 to 0.03 in.	0.06 to 0.10 in.
Less than 300	0.025 to 0.04 in.	0.08 to 0.13 in.
Less than 1000	0.04 to 0.06 in.	0.10 to 0.16 in.

of segments equals 36, the taper would be 10 degrees. It is not practicable, however, to use mica insulation that has not parallel faces; hence the segment is tapered, and any defect in the taper of the latter cannot be made good with insulation. It is found, however, that when the number of segments exceeds 150, bars of the same taper can be used in constructing a commutator having either two more or two less than the designed number.

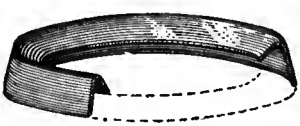


Fig. 47. End Insulating Ring of Commutator

Insulation. It is important to have good insulation between each bar and its neighbor, and especially good insulation between the bars and the sleeve or hub around which they are mounted, as well as between the bars and the clamping devices that hold them in place, since the voltage between bars is not as great as that between the bars and the metal-work of the machine. It is essential that the insulating material be such that it will not absorb oil or moisture; hence, asbestos, plaster, and vulcanized fiber are inadmissible The end insulation rings may be of micanite, or, if for low voltage, of that preparation of paper pulp known as press-board or press-spahn. The conical rings, used to insulate the dovetails on the bottom of the bars from the hub, are usually built of micanite molded under pressure while hot. Fig. 47 illustrates such an end-ring, cut away to show its section.

Commutators using air gaps between the segments as insulation have been tried; but, excepting in the case of arc-lighting machines where the segments are few in number and the air gap large, they have not proved successful, owing to the difficulty of keeping the gaps free from metallic dust.

It is of importance that the mica selected for insulating the bars from one another should be soft enough to wear away at the same rate as the copper bars, and not project above the segments. Amber mica, soft and of rather cloudy color, is preferred to the harder clear white or red Indian variety. The usual thicknesses are as given in Table I.

Commutator Construction. For small machines two common constructions are shown in Fig. 48. The commutator segments are secured between a bushing or hub and a clamping ring, the

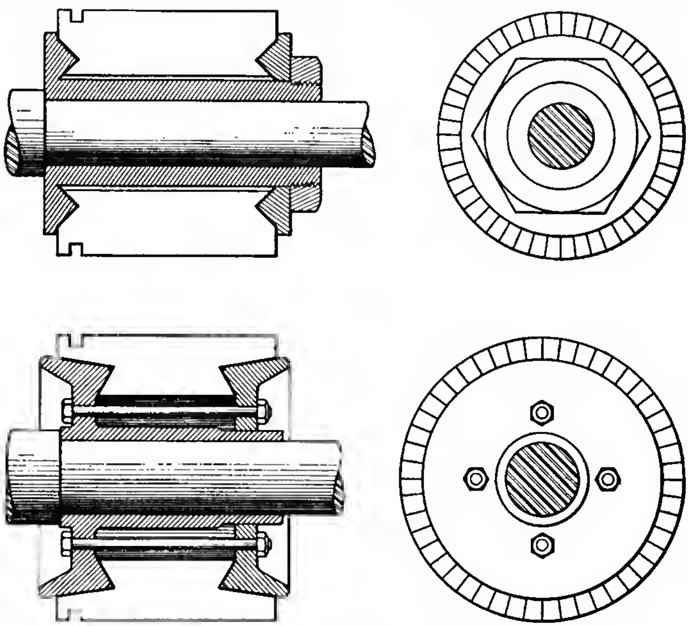


Fig. 48. Common Method of Commutator Construction for Small Machines

latter being mounted on the hub, and forced to grip the bars by means of a nut on the hub or by bolts passing through the ring and hub, as in Fig. 49. The ends of the bars are beveled so that the ring and bushing draw the segments closer together on tightening.

The hub in small machines is usually of cast iron keyed to the shaft; but in large machines the commutator is built upon a strong flange-like support or shell, bolted to the armature spider, Fig. 50, or mounted on a separate spider secured to the shaft, Fig. 51.

When drawn copper strip is used, the design should be such that the available surface for the brushes takes up nearly the whole length of the bar, and the beveled ends should be as simple as possible. With drop-forged segments this is not so important.

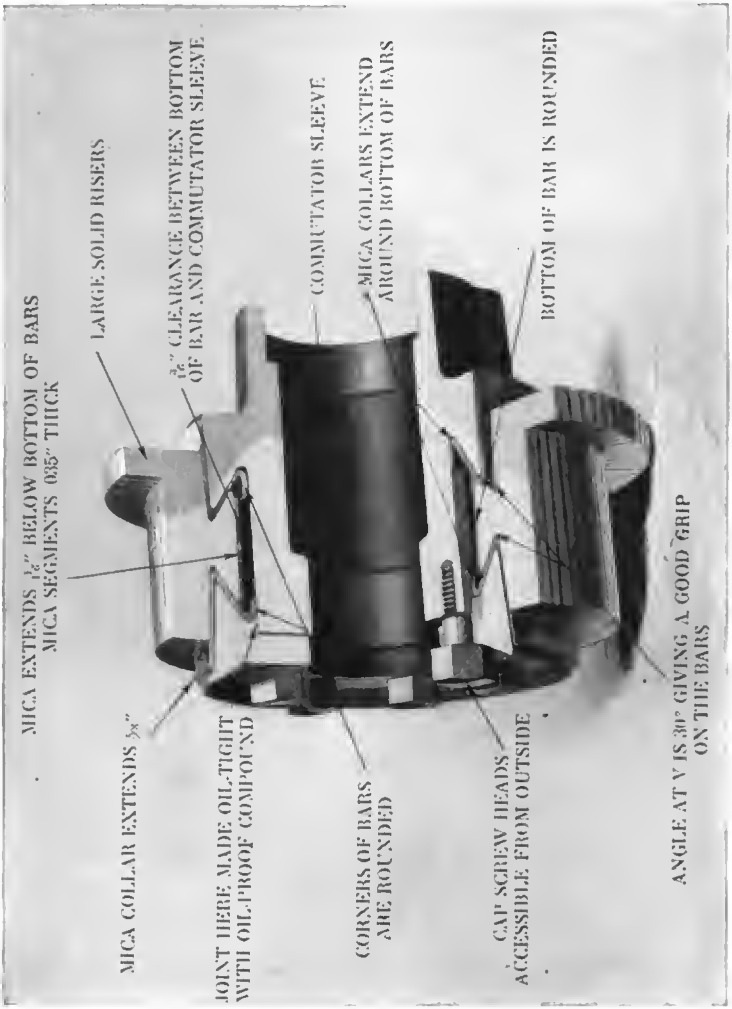


Fig. 49. Commutator for Small Machine Cut Away to Show Construction
Courtesy of Reliance Electric and Engineering Company

In building commutators it is usual to assemble the bars to the proper number, with the interposed pieces of mica, clamping them temporarily around the outside with a strong iron clamp, as

shown in Figs. 52 and 53, or forcing them into an external steel ring under hydraulic pressure. They are then put into a lathe and the interior surface is bored out, after which the ends are

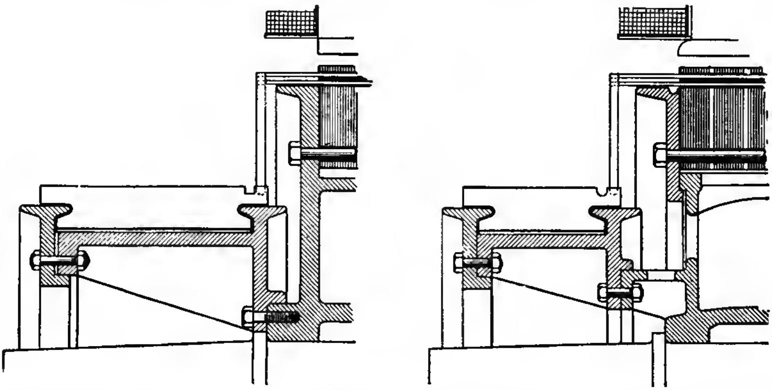


Fig. 50. Commutator Construction for Large Machines. Commutator Spider is Bolted to Armature Spider

turned up in such a way that the angular hollows will receive the clamping pieces. The whole is then mounted with proper insulation upon the sleeve, and the clamping end-pieces are screwed up. It is then heated and the clamps still further

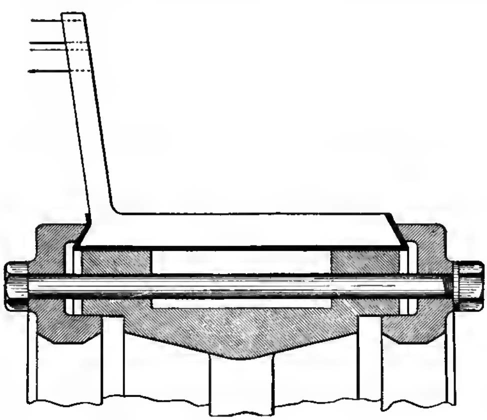


Fig. 51. Commutator Construction for Large Machines. Commutator Spider Is Mounted on Armature Shaft Independent of Armature Spider

tightened up, after which the temporary clamp or ring is removed and the external surface turned up. The commutator shell or spider and clamping ring for a large commutator are shown in

Fig. 54, and the mica insulating rings for same are shown in Fig. 55. Two completed commutators are shown in Figs. 56 and 57.

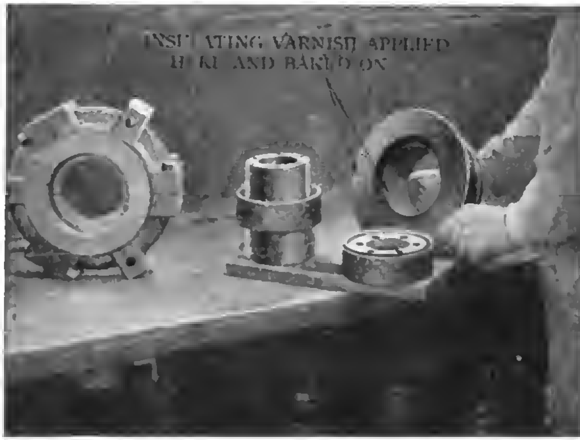


Fig. 52. Method of Constructing and Forming Small Commutator
Courtesy of Reliance Electric and Engineering Company

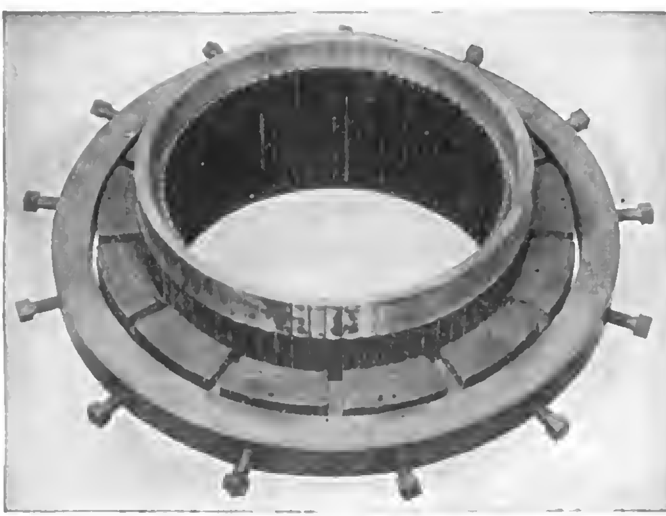


Fig. 53. Method of Constructing and Forming Large Commutator
Courtesy of General Electric Company

Commutator Risers. Connection is made with the armature inductors by means of radial strips or wires, sometimes called

risers, which are inserted into a cut at the corner of each bar and firmly held there by a screw clamp and solder. Figs. 58, 59, and 60 illustrate various modes of making connection to the commu-

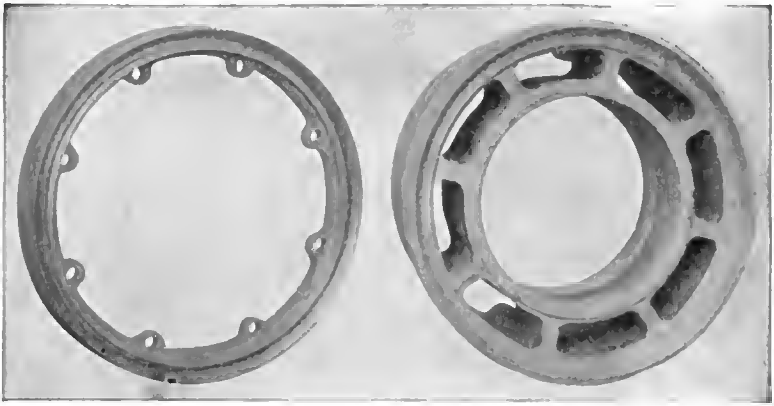


Fig. 54. Commutator Shell or Spider and Clamping Ring for Large Commutator Shown in Fig. 53
Courtesy of General Electric Company

tator bar. The risers are connected to the armature winding in several different ways as indicated in Fig. 61. In some evolute windings no risers are needed, the ends of the evolute being fastened directly to the commutator bars. Similarly, in the case

Fig. 55. Mica Insulating Rings for Commutator Shown in Fig. 53
Courtesy of General Electric Company

of barrel-wound armatures, no risers are needed if the commutator diameter is very nearly that of the armature.

Brushes and Brush-Rigging. Carbon brushes are almost the only type that is now considered. Their shape depends upon the

type of brush-holder selected, and upon whether the brushes are applied to the commutator radially or at an angle. Fig. 62

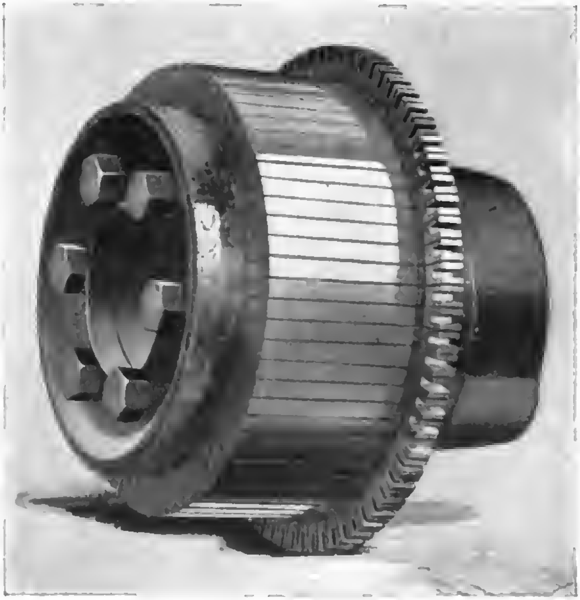


Fig. 56. Completed Commutator for Small Machine
Courtesy of Reliance Electric and Engineering Company

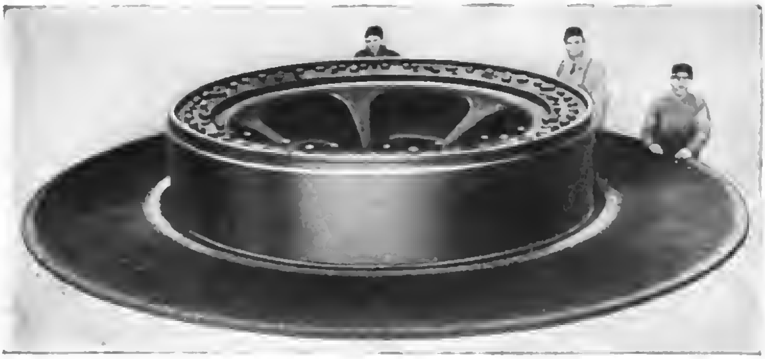
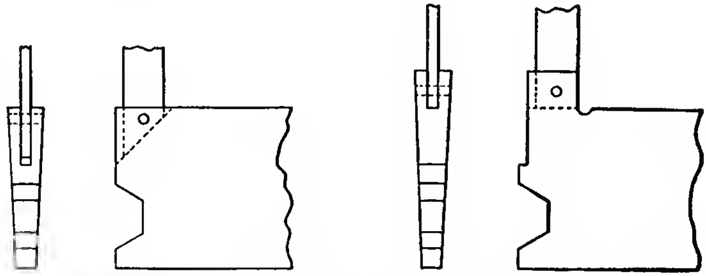


Fig. 57. Completed Commutator for Very Large Machine
Courtesy of Allis-Chalmers Manufacturing Company

illustrates various shapes. The mechanism for holding the brushes must fulfill the following requirements:

(1) The brushes must be held firmly against the commutator, but allowed to follow any irregularity in the contour of the latter without jumping away.



Figs. 58 and 59. Methods of Connecting Commutator Risers to Commutator Bars

(2) The mechanism must permit the brushes to be withdrawn while the commutator is rotating, and must feed them forward as required.

(3) Spring pressure must be adjustable, and the spring must not carry current.

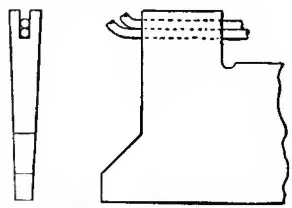


Fig. 60. Armature Winding Connected Directly to Commutator Bar

(4) The springs must not have too

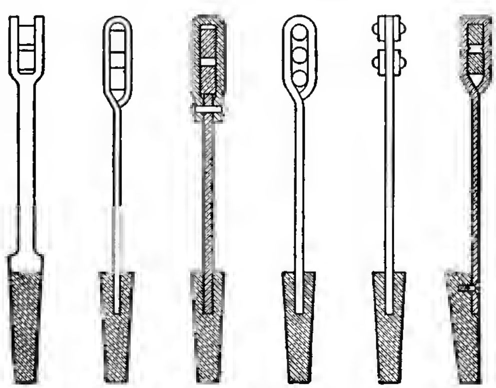


Fig. 61. Methods of Connecting Armature Winding to Commutator Risers

great inertia, or they will not readily fulfill the first condition in regard to following the commutator.

(5) Insulation must be very thorough.

(6) The mechanism must be so arranged that the position of the brushes may be shifted.

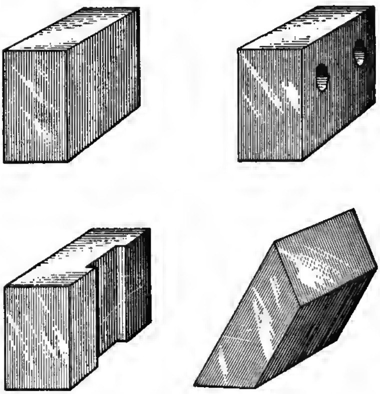


Fig. 62. Several Different Forms of Carbon Brushes

(7) All parts must be firm and strong, so the brushes will not chatter as the result of vibration while the machine is running.

The commercial forms of holders for carbon brushes may be classified under three types: hinged structures, parallel spring holders, and reaction holders.

Fig. 63 illustrates a hinged brush-holder, and an arm holding several. The carbon moves in a light frame, being held against the commutator by a spring whose tension may be adjusted. Connection is made between the brush and the arm by means of a flexible lead, tinned and laid in a slot in the upper part of the carbon. A metal cap placed over the top and sweated in place makes a permanent contact. This is shown by the two illustrations of the brush.

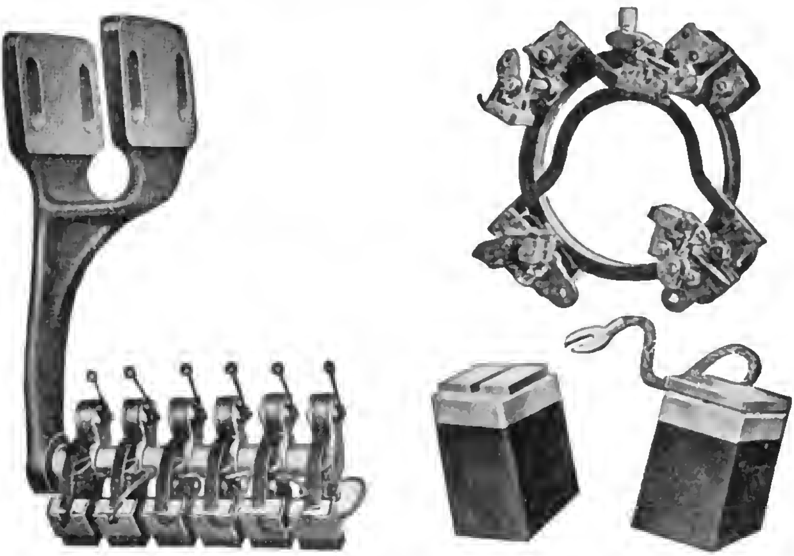


Fig. 63. Brush Rigging and Hinged Brush-Holder

Fig. 64 illustrates a parallel-movement type. The brush is held firmly in the holder by a clamping screw, and the whole arrangement is pressed against the commutator by a pressure

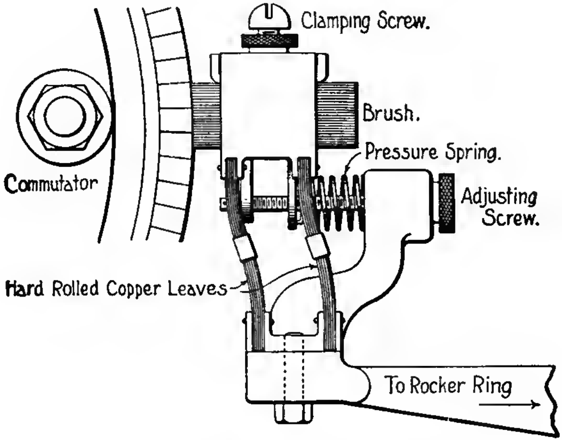


Fig. 64. Parallel-Movement Type of Brush-Holder

spring, whose tension may be varied by means of the adjusting screw. Connection is made between the brush and the stationary part of the holder by means of two sets of rolled-copper leaves which at the same time act as flexible joints.

In Fig. 65 is shown a reaction type of brush-holder. The brush C is pressed against the commutator by the adjustable spring L, the holder B being secured firmly to the rocker arm P by means of the set-screw q. The brush is furnished with a dovetail-shaped groove along its entire inner edge, and into this groove is fitted a screw in the face of the holder B.

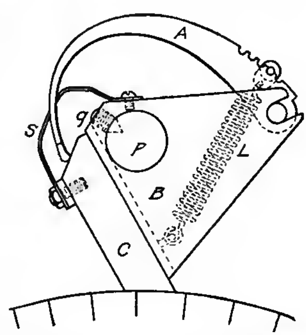
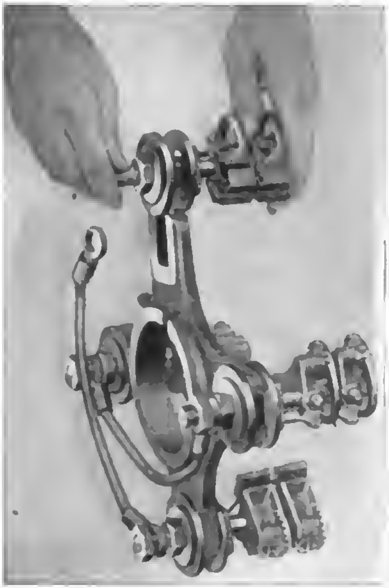
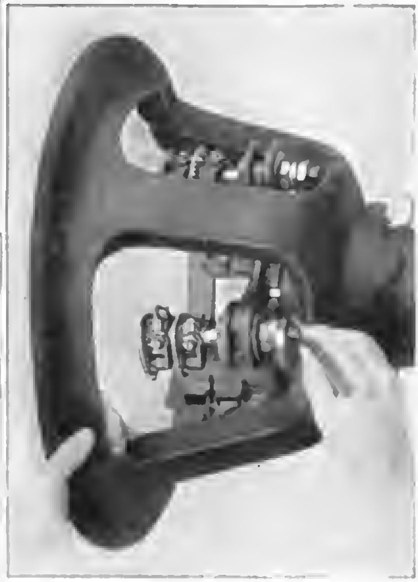


Fig. 65. Reaction Type of Brush Holder

Rockers and Rocker Arms. For small machines the rocker arm is usually clamped upon a shoulder turned upon the bearing pedestal as indicated in Figs. 66 and 67. For large multipolar generators, the rocker arms, that is, the rods on which the brush-holders are held, are fixed at equidistant points around a cast-iron rocker ring, which is itself





Figs. 66 and 67. Brush Rocker Arm for Small Machine and Method of Mounting Same on Bearing Pedestal
Courtesy of Reliance Electric and Engineering Company

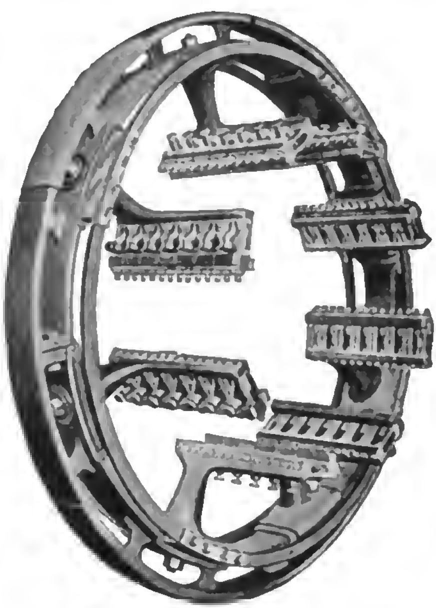


Fig. 68. Rocker Ring and Brush Mounting

supported on brackets projecting from the magnet yoke. This construction is shown in Fig. 68.

Each manufacturer will use a slightly different method or design in supporting the brushes, but the principle of all of them is similar. In Figs. 69 and 70, slots are provided in the brush rocker arm so that the brushes can be shifted to proper position on the commutator and then held securely in place by bolts to the bearing bracket or bearing pedestal. These parts are made quite large in proportion to the stress

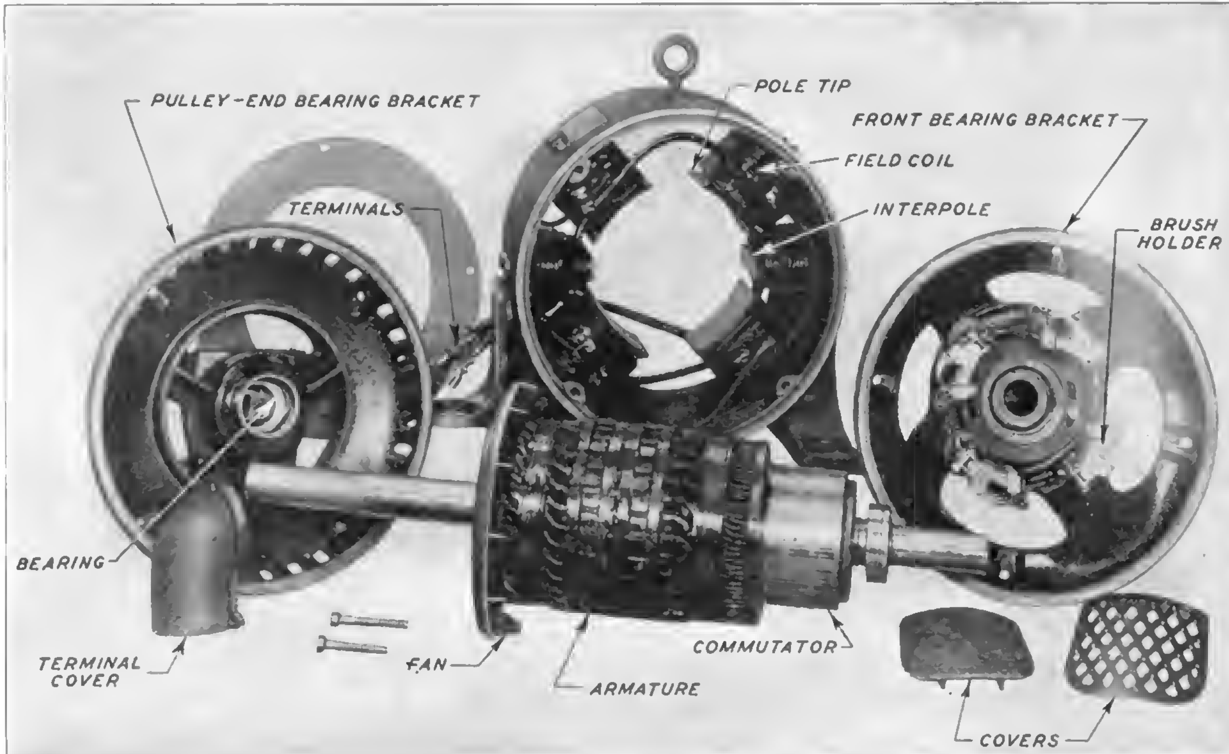
Fig. 69. A Two-Pole Brush Rocker Arm

Fig. 70. A Four-Pole Brush Rocker Arm

Courtesy of Allis-Chalmers Manufacturing Company, Milwaukee, Wisconsin

or strain that they will receive in order that the brushes will not be displaced from their correct position by even a few thousandths part of an inch.

A modified form of the reaction type of brush holder, Fig. 65, is used on nearly all of the present-day machines. This consists of using a box or frame around the brush, Figs. 69 and 70, in order that the brush will not get accidentally knocked out of the proper place on the commutator, as frequently occurs on the type shown in Fig. 65. It is good practice to always use two or more brushes in parallel with each other, instead of one large brush. Then if one brush fails to make good contact on the commutator or sticks in the holder, the other brush will carry the current while it is being cleaned or replaced.



DISMANTLED VIEW OF A 20-HORSEPOWER, 1,150 R.P.M., 230-VOLT, DIRECT-CURRENT MOTOR

Courtesy of Allis-Chalmers Manufacturing Company, Milwaukee, Wis.

ARMATURE WINDING

DIRECT-CURRENT ARMATURES

INTRODUCTION

Winding Terms. Owing to the lack of standardization of terms used by armature winders, there is much variety in the naming of common things and processes. There are many cases in which two or three different terms are used to express the same meaning. Because of this confusion in names, a winder who has secured all his experience at one shop and on one particular kind or type of machine may have considerable difficulty in producing satisfactory work in another shop. A thorough understanding of the use of different materials and fundamental principles will enable him to adapt himself easily to changed conditions.

Types of Armature Windings. There are two general types of armature windings, the open circuit and the closed circuit. The open-circuit winding is used on alternating-current generators and the ends of the winding are connected to collector rings or to the external system. (The open-circuit system was used on the first direct-current generators constructed. The two ends of the coil were connected to commutator bars that made contact with the brushes only when the coil generated its maximum voltage. There was no current flowing through the coil except when it was connected by the brushes to the external circuit.) In the closed-circuit type all the armature coils are connected in series with each other at the commutator bars, and the voltage generated by all the coils is thus added together. This type of winding produces a higher voltage, with the same number of armature conductors or coils, than the open-circuit direct-current type of windings. For this reason it is used on practically all direct-current machines manufactured at the present time.

RING ARMATURE

Use of Ring Armature. The ring armatures are limited almost entirely to generators from ½ kw. to 2 kw. in size and are usually

directly connected to small steam turbines. These outfits are used for lighting purposes on locomotives, steam shovels, oil-well machines, ore handlers, in lumber camps, and similar outdoor work where they are subjected to very rough usage and are handled by those who are not familiar with electrical machinery. A view of such an armature is shown in Fig. 69.

Winding Ring Armature. Before starting to wind an armature it is always necessary to remove any sharp burrs or fins which may exist in the slots of the core. Failure to watch this detail will allow the sharp edge of the laminations to cut through the insulation and "ground" the windings, making it necessary to spend additional time in locating the defective coil. In winding this type of armature one end of the wire is attached to the commutator and the other end is passed through the slot and through the inside of the core, then through the slot again, and so on until the desired number of turns have been wound around the core. The end of the wire is then attached to the adjacent commutator bar. The beginning end of the next coil is attached to this commutator bar and the coil in the next slot is wound in the same manner as in the first slot. This operation is repeated for each slot. The ending end of the coil in the last slot is connected to the same commutator bar as the beginning end of the first coil. When the amount of wire needed for one slot is determined, the correct length is wound on a shuttle or bobbin which can be easily passed under and over the core of the armature. The commutator should be located on the shaft so that the center of the bar is opposite the center of the slot in the core.

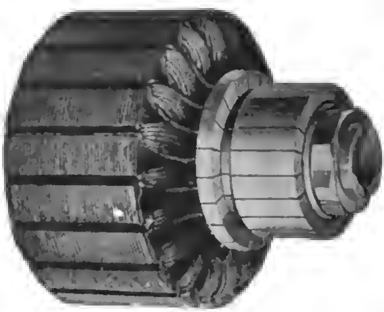


Fig. 69. Ring Armature for a Direct-Current Generator
Courtesy of the Pyle-National Company

In winding these armatures asbestos-covered wire is frequently used, instead of cotton-covered wire, in order to produce a machine that will withstand a higher temperature and not burn out as easily as the ordinary machine. When asbestos-covered wire is used, the leads should be soldered to the commutator bars with a special

solder, which has a much higher melting point than the ordinary solder. When ordinary solder, which is composed of half tin and half lead, is used, the temperature may become high enough to cause it to loosen up and be thrown out from the bars. This makes a poor contact and causes great heating, and in time the leads and commutator bars become red-hot and destroy the machine. The 32-volt armatures instead of being wound with wire are frequently wound with a copper ribbon nearly as wide as the slot. The slots are usually lined with mica, fish paper, or asbestos paper in order to protect and insulate the windings from the core. The completed armature is often dipped in bakelite varnish. This not only makes the armature winding acid-proof, salt-water proof, and moisture proof, but it also enables the winding to operate at a higher temperature. The bakelite varnish fills up all air pockets in the winding and allows the heat to be conducted from the copper out through the insulation and radiated to the air.

DRUM ARMATURES

ARMATURE COILS

There are two distinct types of drum windings or coils used on direct-current armatures—the wound type and the formed type.

Wound Type. In the wound type the correct number of turns are wound by hand or machine directly into the slot. This winding is used on small motors and generators usually of less than 1 horsepower output. The number of slots on such an armature are small, usually less than 20, and the number of turns or conductors will be great and will range from 10 to 100 or more.

Formed Type. In the formed type of winding the conductors are wound on a form and are bound together by means of tape into one coil which is then inserted in the slots. This winding is used on nearly all motors and generators larger than 1 horsepower. The conductors are formed from round and square wire, strap, ribbon and copper bars.

Diamond Coil. This coil derives its name from its shape, which is similar to a diamond, as will be noted by referring to Fig. 70 and the center group of coils in Fig. 71. This type of coil is used more extensively than any other type of coil. The great advantage of this coil is that it can be easily manufactured in large quantities

for standard machines. These coils are all of like size and shape and are symmetrical, and there is no tendency for electrical unbalance to occur. When a wave winding or connection is used in winding a

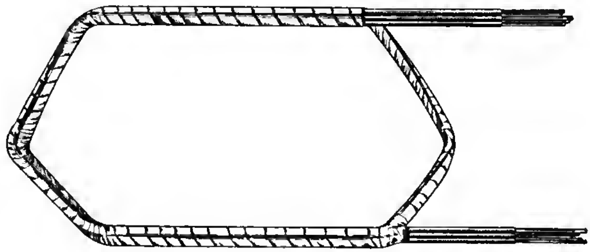


Fig. 70. Diamond Type Armature Coil

direct-current armature, the leads are brought out from the straight portion of the coil as shown in Fig. 70. The leads from the coil are brought out near the point of the diamond, as shown in the center

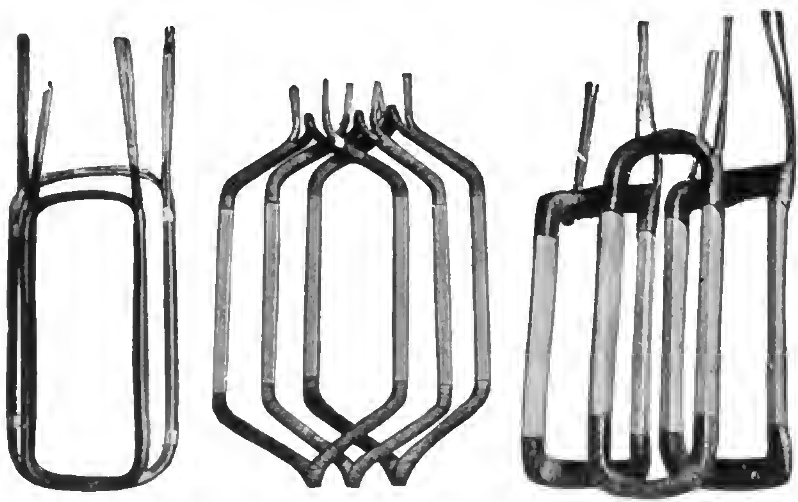


Fig. 71. Concentric and Diamond Type Armature Coils

coil, Fig. 71, when the coil is used on the stator or phase-wound rotor of an induction motor and on a direct-current armature when a lap or multiple connection is used. The conductors are usually first wound on a form in the shape of a long loop or hairpin, as shown at *A* in Fig. 72, and then pulled by means of a coil spreader into the form shown at *B*. This particular coil is three wires wide

and has 5 turns. When there are two or more wires in parallel, square, double cotton-covered wire is frequently used instead of round wire, because a size smaller wire can be used and more space will be available for insulation.

Involute Coil. The involute coil is used mostly on direct-current industrial motors, low-voltage electroplating generators, and the rotors of induction motors. This type of coil is shown at *C*, Fig. 72, with the leads brought out at the point of the involute.

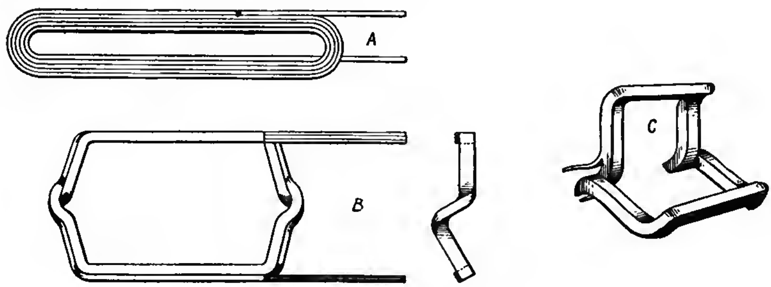


Fig. 72. Hairpin Loop, Diamond, and Involute Coils

The leads can be brought out at the straight part of the coil in the same manner as the diamond coil. It is not easy to insulate these coils properly, due to the number of bends in the coil, and the bends make it difficult to place the coils in the slots of the core. The bar type of coil with involute end connectors is easy to insulate and assemble and is used more extensively than the wire-formed coil. The great advantage of the involute coil is that less space is required for end connections than in any other type of coil and therefore it is used when the armature must be made as short as possible. The involute coil can be punched in one piece from a sheet of brass or copper. It is used extensively on the rotors of induction motors driving electric elevators. A view of this coil is shown in Fig. 73.

Fig. 73. Punched Involute Coil
Courtesy of Roth Bros. and Company

Concentric Coils. The simplest and easiest coil to wind and insulate is the concentric coil shown on the left and right in Fig. 71. The disadvantage of using these coils is the fact that several different sizes are required on the machine; and on all except single-phase machines some of the coils must be bent into two or three different

shapes. This makes it necessary to provide several different forms and molds for winding and shaping the coils. They are not interchangeable and, due to this fact, the number of spare coils necessary for repairs is greatly increased making the cost of manufacture and repair more expensive than with the other types of windings. When

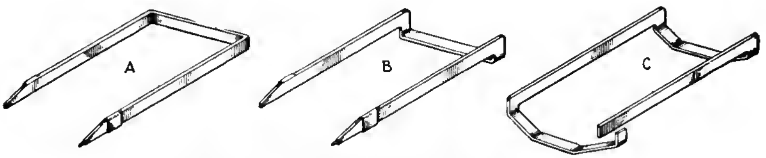


Fig. 74. Concentric Coils for Partially Closed Slots

concentric coils are used on partially closed slots, each coil is shoved through from the end, and the end connectors are soldered on when the coil is in place. In Fig. 74 a view of the straight shoved-through type of coil is shown at *A*. *B* and *C* show coils bent at one and both ends. The coils used for the partially closed slot are of heavy copper

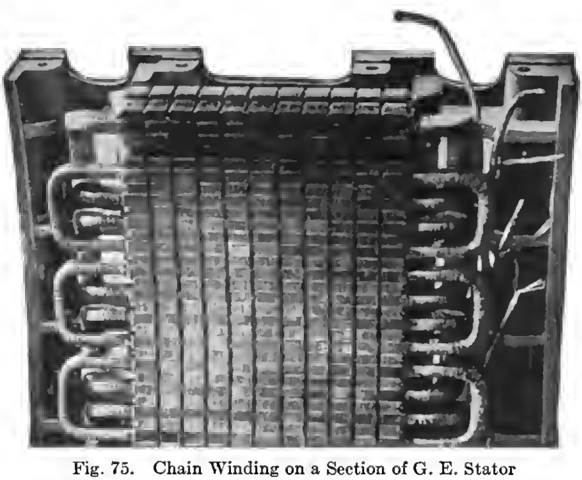


Fig. 75. Chain Winding on a Section of G. E. Stator

ribbon or bars, but round or square wire or thin ribbon is used for the open-type slot. When straight coils and those bent at one or both ends are used in the same machine, the combination is often referred to as a chain winding, Fig. 75.

Threaded-in Coils. The threaded-in type of coil is used very extensively in winding the stators of induction motors because it is

desirable to use the partially closed slot in order to secure as high an efficiency and power factor as possible on this type of motor. The shuttle type of coil is shown in Fig. 76 which also shows that only the ends of the coils are insulated with cotton tape. This

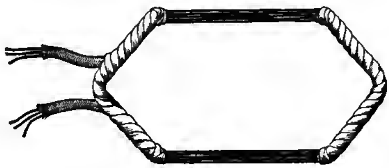


Fig. 76. Shuttle Type Coil

method of insulation allows a few wires of the coil to be passed into the slot at one time. This coil is similar to the coils shown in Figs. 70 and 71 with the exception that only the ends of the coil outside the core are taped.

Forming Coils. The diamond and involute coils are usually wound in the shape of a hairpin or long loop and then pulled into

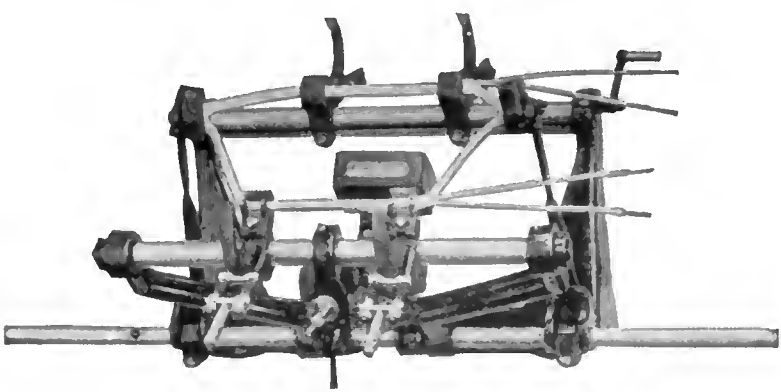


Fig. 77. Coil Spreader or Former
Courtesy of the Armature Coil Equipment Company

the proper shape and size by means of a coil spreader or former, Fig. 77. These machines are adjustable so that the coil will be formed to the same radius as the center of the armature teeth of the core and will have the correct dimensions between the two sides of the coil. After the machine has been adjusted to give the desired coil, any number of coils can be spread or made and they will all be interchangeable. This adjustable machine is advantageous in wind-

ing a number of armatures of the same size. In small shops, where there is not sufficient work to justify the purchase of such a machine, the coils may be pulled to shape by hand. This can be accomplished by using two hardwood blocks about 2 inches square and an inch longer than the length of the core with grooves cut lengthwise of the blocks. The depth of the grooves is $\frac{3}{4}$ inch and the width the same as that of the coil. The first block is fastened in a bench vise and the coil is then slipped into the groove. The coil is spread to the proper distance by pulling on the second wood block with both hands. The desired angle for the sides of the coils is made by pulling this coil above or below the center line of the side of the coil held in the vise. It is usually necessary to make several trials before the correct spread of coil is obtained.

The best method of forming the concentric, basket, or shuttle type of coils is to wind them on a form or mold, such as is shown in Fig. 78. The former is usually made of hard fiber and attached to

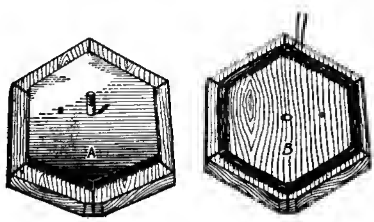


Fig. 78. Wood Coil Former

a maple board about an inch or two larger than the former. Another board or plate, the same size as the maple board, is clamped to the other side of the former by means of the center bolt. This forms a groove in which the wire is wound and gives the coil its correct form or shape. A saw-cut slot is made at the corners of the plates radially inward to the edges of the hard fiber former so that short lengths of cord or wire can be inserted in these slots before winding the coil. The wires of the coil may be held in place by tying the cord or wires after the correct number of turns have been wound on the former. The front plate or board of the former is then unclamped and removed, allowing the coil to be slipped off easily. The width of the groove, which is the thickness of the hard fiber former, is the height of coil in the slot and is determined by the designer of the machine.

INSULATING MATERIALS

Insulated Wire. The wire or ribbon used in winding coils has an insulating covering of cotton, silk, enamel, or a combination of these. On motors and generators larger than 1 horsepower, double cotton-covered wire or ribbon is used almost entirely; but if the space in the slot for the copper conductors is small, single cotton enamel covered wire is used. Enamel, single silk enamel, or double silk-covered wire is used on fractional horsepower motors. In insulating coils and slots it is necessary to provide for both mechanical protection and electrical insulation. The insulation placed in the slot is intended to afford mechanical protection and the insulation on the coil is more for electrical insulation than mechanical protection. In the following paragraphs the most common materials used in insulating armature coils and slots are discussed.

Cotton Tape. This tape is made from a medium grade of cotton and has either a smooth or twilled weaving. It has a soft, starchless finish and is specially treated so it will absorb insulating varnishes and compounds. Its usual thickness is 7 to 10 mils (.007 to .010 inch).

Linen Tape. A good grade of cotton, which has a hard finish and looks like linen, is used to make these tapes. If linen is used in their manufacture, they are known as "Real Linen Tape" or "Irish Linen Tape."

Varnished Cloth. This is a cotton cloth that has been treated with an insulating compound, varnish, or linseed oil, which improves its insulating properties. Often it is called varnished cambric, varnished muslin, empire cloth, or Kabak cloth. Cut into tape widths, varnished cloth is sometimes referred to as linotape. The tape is cut so the threads will be straight or on the bias. The bias-cut tape is more elastic than the straight tape but has only about one-half the tensile strength. The treated cloth and these tapes are made in the usual thickness of 7 and 10 mils.

Paper and Fibers. Express parchment paper, red rope paper, fish paper, pressboard, horn fiber, rawhide fiber, and leatheroid are some of the different kinds of paper insulating materials used in armature winding. The express parchment paper is a high-grade wood pulp paper, free from pinholes or any metallic particles. It is made 5 and 10 mils thick and is used extensively in insulating ribbon

or bar armature conductors. Red rope paper is made of a long-fiber, all-hemp material and does not contain any wood fiber. Cotton rag stock or material, which is very tough and will stand more bending, creasing, and abrasion than any other insulating paper, is used to make fish paper. Horn fiber is made of strong hemp stock or material. The 5- and 10-mil thicknesses are used extensively for lining the slots and the $\frac{1}{64}$- to $\frac{1}{16}$-inch thicknesses as separators, or spacers, between the different coils in the same slot. The $\frac{1}{16}$ to $\frac{3}{32}$ thicknesses are used as top sticks or slot wedges to retain the coils in the slots. Rawhide fiber and leatheroids are very similar to horn fiber except that the rawhide fiber is subjected to a greater pressure in manufacture and is a harder material and not as flexible as horn fiber, but their uses are similar. All these paper insulations can be treated with various insulating compounds, which make them more flexible when first treated. This flexibility allows the coil to be bent to any desired shape. After the varnish or insulating compound has dried, it becomes a hard, dense mass.

Slot and Coil Insulation. The best practice is to insulate both the coils and the slots before inserting the coils. The advantage of this is that insulation which will resist abrasion can be used in the slot to protect the coils from the sharp edges of the laminations of the core, and insulations with high electrical qualities may be used on the coils. The coil is usually insulated when the wires can be uniformly arranged in the slot. It is not necessary to use as thick a slot insulation with an open slot core as when the threaded-in type of coil is used on an armature having a partially closed slot. In the latter case the maximum slot insulation given in the following table should be used.

Operating Voltage	Slot Insulation
6 to 50	.010 to .025
50 to 250	.010 to .035
250 to 500	.020 to .045
500 to 1000	.030 to .060
1000 to 1500	.040 to .075

KINDS OF WINDINGS

Lap Winding. A lap winding derives its name from the fact that the leads or ends of the coils, connected to the commutator bars,

lap back toward each other and are usually connected to adjacent bars. It will be seen in Fig. 79 that leads from the coils in slots 1 and 5 are connected to commutator bars 1 and 2. The dark lines represent the bottom part of the coils and the light lines the top part of the coils. When the armature winding is completed, only the top part of the coils can be seen. Frequently this winding is referred to as a 1 to 2 connection, but a better name for it is multiple, or parallel, winding, because there are as many circuits from the positive to the negative brushes as there are field poles. Multiple, or parallel, winding requires as many sets of brushes on the commutator as field poles and the connection is sometimes referred to as a 4-brush (4-B) or 6-brush (6-B) connection, when used on a 4-pole or 6-pole machine.

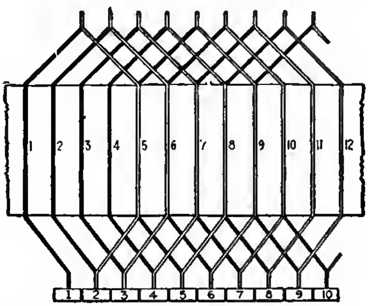


Fig. 79. Diagram of Connections for a Lap Winding

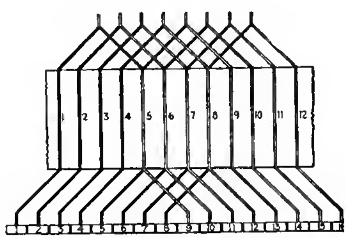


Fig. 80. Diagram of Connections for a Wave Winding

Wave Winding. The zigzag or wave-like shape of the coils on the armature gives the wave winding its name. This is shown very well in Fig. 80, but it must be remembered that on a completed armature only the light-colored coils can be seen. The winding is often referred to as a series, or two-circuit, winding because half of the armature coils are connected in series and the two halves are in parallel with each other. There are only two current paths through the armature winding and only two sets of brushes are necessary regardless of the number of poles on the machine. This connection is also frequently called a 2-brush (2-B) connection. In actual practice there are usually as many sets of brushes on the commutator as there are field poles in order to reduce the amount of current that each brush must carry. In Fig. 80 it will be seen that the coil in slots *1* and *5* is connected to commutator bars *1* and *9*. The next

coil in the circuit would be in slots *9* and *13* and connected to bars *9* and *17*. This type of winding is used on all railway motors and on machines of small and medium size, when it is desired to keep the number of coils to a minimum.

COIL PITCH AND COMMUTATOR PITCH

The coil pitch or the winding pitch is the distance spanned by the two sides of a single coil. It is usually given in the number of slots spanned or the slot numbers in which the sides of the coil are placed. In Figs. 79 and 80 the coil pitch is 4 slots and is referred to as a 1-5 pitch. When referring to a complete armature winding diagram, the coil pitch is often expressed in the number of coil sides spanned by the coil. It is easier and less confusing for the armature winder to have the coil pitch or throw of the coils expressed in the slots in which the coil is placed. The distance between the centers of two adjacent field poles is called the pole pitch. When a coil spans this distance it is called a full-pitch coil. The distance expressed in the number of armature slots spanned is equal to the total number of slots on the armature divided by the number of poles. Assume, for illustration, that a certain 4-pole machine has a 44-slot armature. The full coil span would be 44÷4 or 11 slots or a 1-12 throw of coil. If the coil throw should be made 1-11 or 1-10 it would be called a fractional-pitch, short-pitch, or short-cord winding. The fractional-pitch winding is used very extensively because the length of the end connectors of the coils are reduced, armature reaction is reduced and, in an alternating-current generator, a sine wave is more nearly obtained.

The commutator pitch is the distance spanned by the leads to the commutator bars. It is expressed by giving the number of the bars to which the leads from one coil are connected. In Fig. 79 the throw of the leads or commutator pitch is 1-2 while in Fig. 80 the pitch is 1-9. In a lap winding the commutator pitch is usually 1-2, 1-3, or 1-4 while in the wave winding the pitch is always much greater, being equal to the number of commutator bars + or − 1 divided by the number of pairs of poles.

ELECTRICAL DATA

There are a number of different methods of conveying the desired armature winding information or data which vary from the

simple tag shown in Fig. 81 to a very elaborate drawing. Where a special connection is desired, such as is necessary when the brushes are located between the pole pieces instead of on the center line of the poles, a drawing is almost necessary. Fig. 82 gives the same data as Fig. 81 but, in addition, shows how to locate the commutator in relation to the winding in the slot. This style of connection is used extensively when the brushes are located under the center of the field poles as shown in Fig. 82. The dotted line from slots 2 to 6 shows the location of the field pole and its relation to the position of the brushes. The heavy dotted line represents the part of the coil in the bottom of the slot and the full line is that part of the coil in the top of the slot.

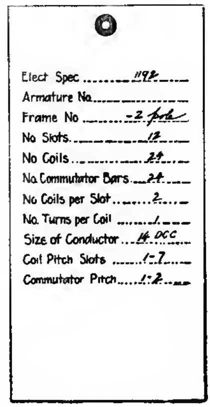


Fig. 81. Armature Winding Tag

WINDING SMALL ARMATURES

Kind of Wire. The majority of small armatures used on electric fans and household appliances have the insulated wire wound directly in the slot by hand or by machine. These armatures are usually less than 4 inches in diameter, have from 10 to 25 slots and use No. 16 to 36 B.&S. gage single insulated copper

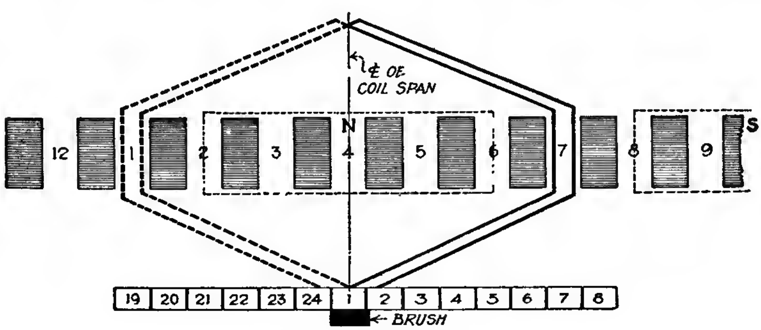


Fig. 82. Armature Winding Diagram

wire for the windings. A double cotton (DCC) or a single cotton and enamel (SCE) insulation is used on sizes 16 to 28 wire, but double silk (DSC), single silk enamel (SSE), or enamel insulations are used on the 28 to 36 sizes of wire. The use of enamel insulated wire has

increased rapidly in the past few years and is giving as good satisfaction as double silk-covered wire.

Insulating the Core. The burrs or fins on the armature punchings are very sharp and cut through the slot insulation easily, so after securing the electrical data and armature, all the sharp burrs or fins in the slots are removed as well as the sharp edges at the end of the slot. By giving close attention to this detail the number of grounded armatures will be reduced to a minimum. After removing all the burrs and the filings from the slots, one or two large fiber headers or washers are slipped over the shaft and pressed up against each side of the core. These headers are usually from $\frac{1}{32}$ to $\frac{1}{16}$ inch thick. They are generally made with the same punch and die as the sheet-steel laminations and resemble an armature

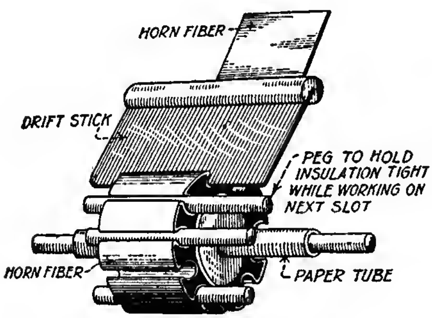


Fig. 83. Method of Insulating the Core

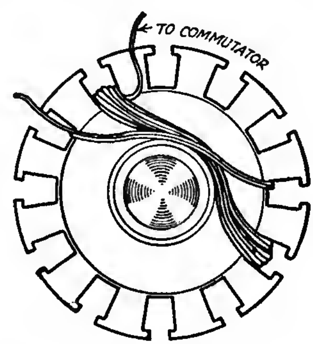


Fig. 84. Winding a Small Armature

punching. The next operation is to place insulation in the slots. The continuous strip method shown in Fig. 83 is best adapted for this size of armature. A continuous strip of fish paper, horn fiber, or leatheroid about .010 of an inch thick and about $\frac{1}{4}$ to $\frac{3}{8}$ inch wider than the length of the armature core is used. Insert one end in a slot and hold it in place with a peg so that the insulation can be pulled tight. Crease the insulation over the edge of the slot and with a drift stick force the insulation into the next slot as shown in Fig. 83. The next peg is inserted in the slot, then the insulation is pulled tight and creased over the edge of the tooth. The remaining slots are insulated in like manner. The creasing of the insulation over the edges of the teeth will cause it to hold in place and to fit snugly against the sides of the slots. Leave the first pin in place

until the insulating of the slots is completed. When the third slot has been insulated and a peg placed in it, the second peg can be removed and used in the fourth slot, and so on, only three pegs being needed. The first and last ends can be joined together outside the slot with shellac or some other sticking compound, although this may be dispensed with if the ends are flared like a funnel. Never use liquid glues for sticking the ends together, because most of these glues contain a small amount of acid which, in time, will corrode the copper wire.

Where it is desired to use empire cloth or oiled muslin insulation in addition to the fish paper, the two strips can be fitted in the slots in the same manner as the first strip. The empire cloth, being the upper strip, is always placed next the wires. When it is desired to insulate between the top and bottom coils in a slot, the method described will work satisfactorily but smaller and correctly shaped pegs must be used. The first coil will always lie in the slot diagonally and the shape of the peg should be such as to take care of this.

Winding the Coils in Slots. This particular armature is for a 2-pole motor, with 12 slots and 12 coils, each coil having 20 turns. The coil pitch is slot 1 to slot 6. In order that it can be easily handled by the men, the wire for winding the armature is furnished on small spools weighing from 2 to 3 pounds. The end of the wire is fastened around the shaft beyond the commutator. As it is unrolled from the spool it is passed through slot 1 to the back end of the armature, across to slot 6, then through to the front end, across to slot 1 and then through the slots again in the same manner as the first turn. The winder must watch carefully and see that the wires are arranged in the proper order, or rows, in the slots, Fig. 84, and that the different layers fit snugly. It is often impossible to arrange the layers uniformly across the bottom of the slot. In such cases where the armature has a fractional pitch winding, the wires can be built up in layers from the nearest corners of the two slots. When the required number of turns for that coil has been wound in the slots, the wire is looped back about 2 to 3 inches beyond the commutator. The loop to the commutator is given from three to five half-turn twists in order to hold the two wires close together and enable cotton sleeving to be easily slipped over them, providing additional insulation when desired. The sleeving should extend to the

inside of slot. The next coil is wound in slots 12 and 5 in the same manner as the first coil. The first 5 coils wound on the armature will be located in the bottom of the slots, and a strip of empire cloth or fish paper is inserted in the slots above the wires in order to separate the top and bottom coils. This insulation can be inserted in the same manner as in the bottom of the slot, or a strip twice the width of the slot and bent in a U-shape can be slipped in the slot. The rest of the coils are wound in the same manner. The end of the lead from the last coil and the lead fastened around the shaft from the first coil are given several half turns to hold them together.

The winding is next tested for grounds by connecting the terminals of a testing transformer to the copper wire and the core and applying the desired voltage. Where no testing transformer is available, the winding can be tested by connecting the proper number of lamps in the leads from the electric light or power circuit and attaching them to the winding and the core. The lamps are used to limit the current taken from the power circuit to a safe value, in case the windings are grounded. Without the lamps a short circuit would be placed on the power circuit. If the filament of the lamps becomes red it indicates that the winding is touching the core and the defective spot must be located and repaired. The defective coil can be located by cutting the loop on the end of the leads from the coil and testing between each coil and the core. The grounds are usually located at the ends of the slots and can often be repaired by inserting a piece of mica or leatheroid between the core and winding. If the winding is free from grounds, the slot insulation is trimmed and folded over the wires in the slot and a slot wedge, or fiber top stick, is driven in between the insulation and the tips of the teeth which extend over the slot.

Connecting Winding to Commutator. There are two important facts which the armature winder must know before attempting to connect the coil leads to the commutator bars. The first thing to find out is whether the brushes are located on the center line of the poles, exactly midway between the center lines of adjacent poles, or in some other position. The majority of small motors has the brushes located either on the center line of the poles or midway between the center lines, but nearly all large generators and motors have the brushes located on the center line of the poles. There is

usually provision made on the large generators and motors whereby the brushes can be adjusted to the correct position. This is not the case in railway, mine, vehicle, or small motors, and greater care must be used on these types in connecting the coils to the commutator bars in order to secure satisfactory service from these motors. The second important fact is whether the coils are connected for a lap winding or for a wave winding. The wave winding is used more than the lap winding on railway, mine, and vehicle motors and also on the small starting motors on gasoline automobiles.

In this particular armature there are 12 coils and 12 commutator bars with the brushes located under the center of the poles. Then locate the point on the core midway from the slot in which the coil is located and locate the commutator on the shaft so that

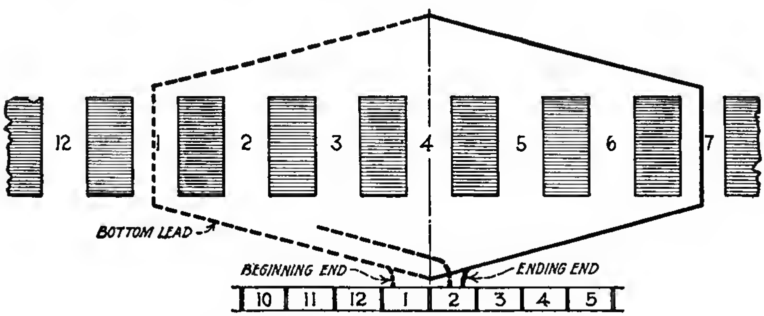


Fig. 85. Diagram of Connections to Commutator

the mica between the bars will be on this center line. Call the bar to the left of the center line 1 and the one to the right 2, as in Fig. 85. Now connect the bottom lead, or beginning end, of the coil in the bottom of slot 1 to bar 1 and the ending end of that coil to commutator bar 2. The beginning end of the bottom coil in slot 2 is also connected to bar 2. This operation is repeated for all leads until they are connected to the commutator. In winding this armature the ending lead of the first coil and the beginning lead of the second coil are twisted together so these two leads can be considered as one connection to be attached to the commutator bars. It is very important that the coils are connected in the proper order to the commutator bars or the motor will heat up very rapidly and there will be considerable sparking at the commutator. In Fig. 85 the coil has a pitch of 1-7 while in Fig. 84 the pitch is 1-6 which is a

fractional pitch winding. These armatures are used on a 2-pole machine.

Testing Armature Windings. The next step after connecting the lead to the commutator is to test the windings for short circuits, open circuits, and grounded or reversed coils.

Bar-to-Bar Test. The bar-to-bar test is a rapid and sure method of locating these defects. The method of making the test is the same for any armature, no matter whether it is a ring-wound armature or a drum-wound with lap or wave windings. A source of direct current is connected to two points on the commutator as shown in Fig. 86. The direct current can best be obtained from the

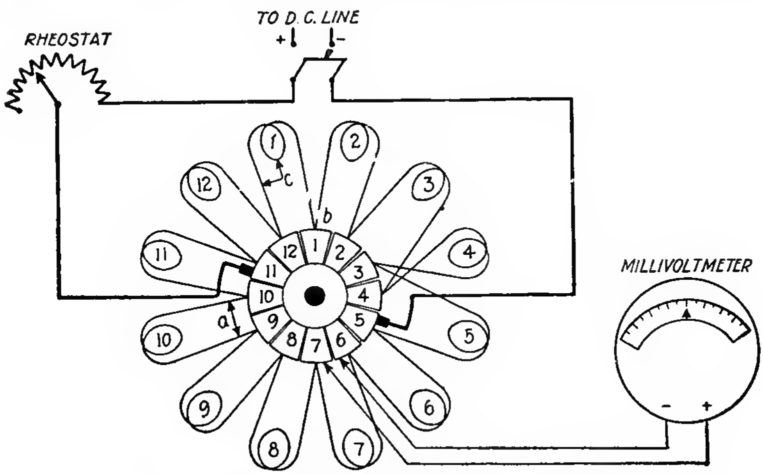


Fig. 86. Diagram of Connections for Testing Winding

115-volt lighting circuit, although where this is not available a number of 6-volt or 12-volt batteries may be connected in series to give the required current. A rheostat is inserted in the circuit in order to regulate the amount of current passing through the armature and thus prevent overheating of the windings. The two leads from a direct-current millivoltmeter are touched to two adjacent commutator bars and the current adjusted until a quarter to a half of a full scale reading is obtained on the meter. The millivoltmeter leads are then touched to bars 7 and 8, 8 and 9, etc., all around the commutator, and if about the same readings are obtained from adjacent bars the winding is connected properly. If there is only a very

small deflection on the meter or none at all when the leads are connected to bars 9 and 10, it indicates that coil 10 is short-circuited. If no deflection is obtained on the meter, the short circuit may be due to copper chips or dust forming a path over the mica insulation. When the test is made after the leads are soldered to the commutator bars, the short circuit will nearly always be due to the solder flowing over the mica to the adjacent bar. This solder can be filed or scraped off.

When the millivoltmeter leads are touched to bars 11 and 12 and to 12 and 1 and there is no deflection of the pointer of the meter, but when the leads are touched to bars 1 and 2 the pointer is thrown violently off the end of the scale, either an open circuit in the coil connected between these two bars has occurred or a wrong connection of the leads to the bars has been made. The defect can be determined by bridging the mica between bars 1 and 2 with a short piece of copper wire and noticing whether a spark is obtained when the wire is removed. The obtaining of a spark will indicate that there is an open circuit in the coil. Another method of determining whether the defect is an open or reversed coil is to reduce the current through the armature until the drop between bars 11 and 5 can be read on the millivoltmeter and then touch the leads to bars 1 and 2. If the drop across these two bars is the same as from bar 11 to 5 the open circuit is in this coil, but if the drop is only $\frac{1}{10}$ to $\frac{1}{2}$ of the reading across bars 11 to 5 it would indicate reversed coils. It is sometimes possible to locate the open circuit, especially if it is in the leads, by attaching the millivoltmeter to bars 1 and 2 and hammering and pressing the armature leads and the winding with the hands. In Fig. 86 the defect is at *b*. When the open circuit is in the body of the coil, it is usually necessary to remove the coil and rewind it. After this defect in armature coil 2 has been repaired, the remaining coils can then be tested.

If, when the millivoltmeter leads are touched to bars 12 and 1, only half the usual deflection is obtained, it is indicated that either half the turns in the coil are short-circuited or only half the correct number of turns are wound in this coil. Should this number of turns be omitted, it may be easily detected by looking at the coil. If only a few turns are omitted or shorted, as indicated by the meter reading, it is necessary to use other tests to locate the defect.

If the deflection of the millivoltmeter needle is very much greater when connected to bars 2 and 3 than when connected to other bars, it indicates that there is a very poor connection between the coil and commutator bars, wrong connection of the coil leads to the commutator bars, a greater number of turns placed in that coil, or a smaller size of wire used. In this case the millivoltmeter deflection is exactly twice the usual reading, indicating that the leads of the coils to bar 2 or bar 3 have been interchanged. Connecting the millivoltmeter leads to bars 3 and 4 gives a reversed reading which shows that these are the reversed leads.

It will be found in testing armatures which have the wire wound directly in the slot, Fig. 84, that the millivoltmeter reading will not be the same for all bars. This is because more wire is used in winding the last coil, which is wound on top of the other coils. The millivoltmeter reading will be lowest for the first coil and greatest for the last. This condition will be most noticeable on armatures wound with a large number of turns or when fine wire has been used. There should be a gradual increase or decrease in the readings for the different bars except that there will be a big change between the readings for the bars connected to the first and the last coils. If not kept in mind this change may easily cause one to believe that there is a defect in the coil. A similar variation is sometimes obtained on large armatures when other than an even number of turns per coil is used. Frequently, such windings as $1\frac{1}{2}$, $1\frac{1}{3}$, or $1\frac{2}{3}$ turns per coil are specified by the designer. In the case of $1\frac{1}{2}$ turns per coil, one coil will have 2 turns, the next coil 1 turn, the next 2 turns, etc., and one millivoltmeter reading will be high, the next one low, the next one high, etc. When $1\frac{1}{3}$ turns per coil are used, the number of turns per coil will be 2, 1, 1, 2, 1, 1, 2, 1, 1, etc. For $1\frac{2}{3}$ turns per coil the order will be 2, 1, 2, 2, 1, 2, 2, 1, 2, etc., and the readings will be high for the 2-turn and low for the 1-turn coils.

Testing for Grounds. The armature winding is tested for grounds by connecting one terminal of a testing transformer to the commutator and the other terminal to the end of the shaft or core and supplying the desired alternating current voltage for one minute. There is a small fuse or circuit breaker in the primary or low voltage side of the transformer which, in case the insulation is

defective, will blow or the circuit breaker will open. Often the location of the defect or ground may be located by observing a spark or smoke which occurs at the defective spot when the circuit breaker opens. The location of the ground may also be located by use of the apparatus shown in Fig. 86, except that one brush is connected to the shaft and the other one to the commutator. One of the millivoltmeter leads is connected to the shaft and the other lead is touched to the different commutator bars until the bar is found which gives the lowest reading, or no reading at all.

Dielectric Test. The voltage to be used in testing the insulation on the armatures is that recommended in the Standardization Rules of the American Institute of Electrical Engineers in section 500 which is as follows:

> The standard test for all classes of apparatus, except as otherwise specified, shall be twice the normal voltage of the circuit to which the apparatus is connected, plus 1000 volts, applied for one minute.

One exception to the above rule is for motors of less than one-half horsepower which are used on household appliances, such as washing machines, vacuum cleaners, etc., on which a test voltage of 900 is applied for one minute.

It is customary to use a slightly higher voltage on the test in the factory in order to insure that it will not fail on final test. In case a higher voltage is used, it is not necessary to apply the test for one minute. The test voltages recommended for shop use for different kinds of motors and generators operating at various voltages is given in Table I. Most testing transformers are provided with steps of 250 volts each. If the transformer is not provided with a tap for that particular voltage, use the next higher voltage.

Testing for Short Circuits. The best way to locate short-circuited coils in an armature is by the use of a small transformer, frequently called a "bug" or "growler." The growler is placed on the armature core over the coils and an alternating current passed through its windings. It will then act as a transformer and generate a voltage in the winding of the armature. If the insulation of the coils be perfect, no current can flow through the armature windings, which then become the secondary of the transformer. Should one or more turns of the armature coil be short-circuited,

TABLE I

Rated Voltage	Test Voltage	
	60 Seconds	2 Seconds
0 to 25	1000	1250
26 to 150	1250	1500
151 to 300	1500	2000
301 to 500	2000	2250
501 to 650	2250	2500
651 to 1000	2500	3000

a heavy current will flow through that part of the winding causing the defective coil to heat up. The defective coil may be located by passing a piece of sheet metal around over the various armature coils and where there is a short-circuited turn in the coil it will cause the sheet metal to vibrate or be attracted when it is over the slot containing the defective winding. This outfit is a great help in testing the windings after the leads have been soldered to the commutator, because if there is sufficient current induced in the armature winding it will often melt the solder that extends across from one commutator bar to the other and remove the defect from the armature. If it is desired to see the effect of a short-circuited coil, the two commutator bars can be short-circuited with a screw driver or a short piece of wire and the same result will be obtained as when there is a short-circuited coil. It is possible with this apparatus to locate or detect one short-circuited turn in an armature coil.

Constructing Growler. The construction of such a device for use on an armature having a diameter of about 4 inches is shown in Fig. 87. This device is usually constructed by using a pole piece from the motor having an armature of corresponding size and cutting a slot about halfway through from the inner diameter of the pole piece. This will leave a core about an inch thick and the full length of the armature or pole piece. Several layers of empire cloth or linotape are wound around the core and the sides are insulated with pieces of horn or rawhide fiber about $\frac{1}{16}$ of an inch thick. Generally the groove is wound with as many turns as possible of No. 10 B.&S. gage, double cotton-covered magnet wire. This will enable the growler to be operated from a 110-volt alternating-current light circuit.

By experimenting, a size of winding can be designed that will produce a voltage from two to three times as great between commutator bars as that which actually occurs in practice. This has an advantage in that the coils are subjected to a higher voltage than actually occurs in practice. The higher voltage will cause any slight defects which are likely to develop to be indicated at this time.

A growler of larger size can be constructed to take care of the larger armatures and, by using two or three different sizes, it is

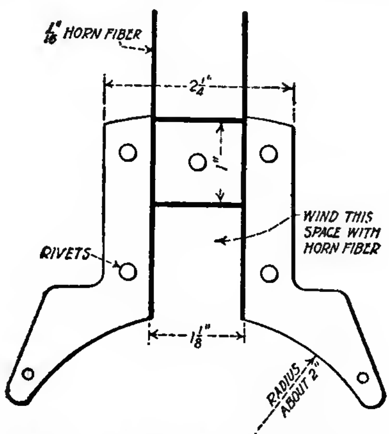


Fig. 87. Small Testing "Bug" or "Growler"

possible to take care of the complete range from a motor of small size to a 20- or 30-horsepower motor. In the larger growlers a smaller number of turns is used but the wire is of larger size.

The construction of another type of growler is shown in Fig. 88. It is used very extensively for small armatures because it can be set on a bench and the armature placed on top of it. In building this growler the laminations, which are 5 by 6 inches, are assembled and held in place by clamps while the bolt holes are being drilled. After bolting the laminations together, the block thus formed can be placed in a milling machine or a shaper and the slots for the coil cut out. When such machines are not available, the two sides of each slot may be cut with a hack saw and, by removing the bolts, the bottom of the slot can be cut out with a sharp cold chisel, using the first one of the laminations for a template or guide. The lamina-

tions can then be reassembled and held together by $\frac{1}{4}$-inch bolts which are insulated from the laminations by paper bushings and washers. The burrs are then removed from the inside of the slot with a file, and the laminations shaped to the desired radius. The core of the growler should be insulated with a fiber sleeve to protect the winding from the core. When the growler is to be used on a 110-volt, 60-cycle circuit, it should be wound with 150 turns of No. 10 B.&S. gage square double cotton-covered magnet wire. For a 220-volt, 60-cycle circuit, 300 turns of No. 13 wire is used; and for a 110-volt, 25-cycle circuit, 350 turns of No. 14 wire is used. After each layer is wound, it should be painted with an insulating varnish,

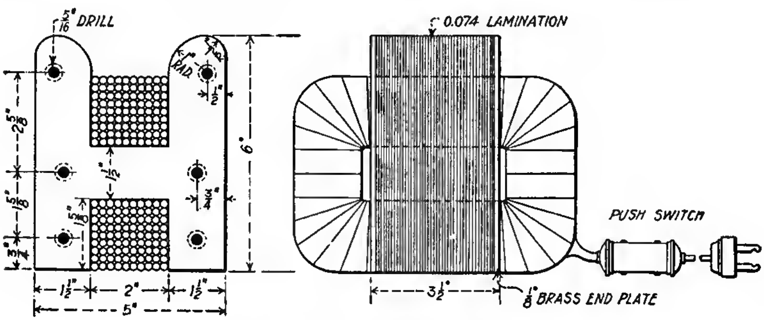


Fig. 88. 11-Type "Growler"

such as bakelite, and then baked in an oven the same as the armature coils. A snap or push switch should be placed in the connecting cord to shut off the current when shifting the armature or growler. The current should be turned on only when there is an armature across the core, because it takes three to five times as much current without an armature as with one.

Other Uses of Growler. The growler can also be used for locating reversed leads to the commutator and open coils by connecting a telephone receiver to two or three adjacent commutator bars and slowly revolving the armature, meanwhile keeping the testing leads in the same position with relation to the growler. A change in the tone of the telephone receiver will indicate a defective coil. Whenever it is possible, the contacts for the leads to the telephone receiver should be supported on a fixed arm so that their position will not change while testing the armature.

WINDING A MEDIUM-SIZED ARMATURE

Standard Ratings. The general method of procedure in winding a medium-sized armature is similar to that described for a small armature in the preceding pages. The details are, however, entirely different. Each coil of a medium-sized armature is wound with the desired number of turns and is insulated before being placed in the slots of the armature. The diamond type of coil is used almost entirely.

The output of a medium-sized armature is from 1 to 50 horsepower at a voltage of from 60 to 600 volts. The standard voltages for direct-current generators are 125, 250, and 600, while the standard voltage ratings for motors are 115, 230, and 550 volts. The generator voltage is about 10 per cent higher than the motor voltage because the circuits are usually designed for a 10 per cent voltage drop between the generator and the motor.

Insulating Coils. The coils are usually wound in the form of a hairpin loop, as shown at *A* in Fig. 72, and then spread to the de-

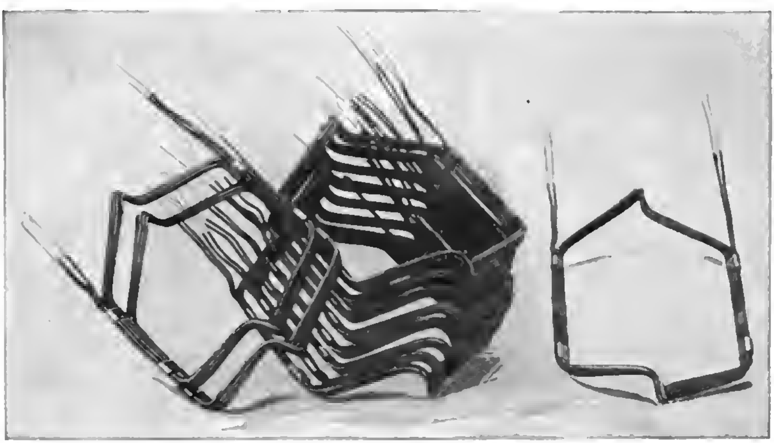


Fig. 89. Formed-Wound Coils Ready to be Taped
Courtesy of the Reliance Electric and Engineering Company

sired shape by means of the machine shown in Fig. 77. The coils are frequently wound on a former to give the desired shape, Fig. 89. It will be noted that these coils are composed of four turns of two cotton-covered wires wound side by side. The two wires of each lead can be connected to the same commutator bars and thus

connect the two wires in parallel with each other, or each wire may be considered a separate coil and connected to different commutator bars. The two wires will be connected in parallel when the number of commutator bars, slots, and coils on the armature are the same, and there will be two coils in each bundle or slot when there are twice as many bars on the commutator as there are slots in the core of the armature. In Fig. 89 it will be seen that there are four bands used to hold the wires in place until the coil is taped. These bands are made from sheet lead about $\frac{1}{32}$ of an inch thick and can be easily attached or removed from the coil when desired. The coils, after

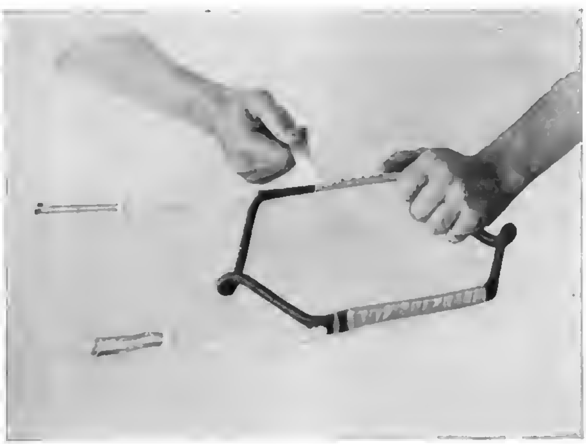


Fig. 90. Taping Coils by Hand
Courtesy of the Reliance Electric and Engineering Company

being formed to the desired shape, are heated in an oven and, while hot, dipped in a tank containing amber-colored baking insulating varnish. They are then placed in an oven heated to about 100 degrees centigrade (212 degrees F.) and allowed to bake until dry. When dipping the coils, care must be taken not to permit the ends of the leads to enter the compound because it is very difficult to remove this insulation when connecting the leads to the commutator and it also makes it difficult to solder the leads to the commutator. In Fig. 89 the light-colored tips of the leads have not been dipped in the varnish, while the dark portion of the leads and coil have been. The insulating varnish penetrates the cotton covering on the wire and binds the wires together so that they cannot easily shift their position.

Taping Coils. Cotton sleeving is slipped over the two wires forming the leads, as shown in Fig. 90, and the whole coil is taped with half overlapping cotton tape. The sleeving should extend into the coil about ½ inch from where the leads leave the coil, and 2 or 3 turns of the tape should be taken around the sleeving at this point in order to fasten it securely to the coil. In Fig. 90 the operator is winding the tape on the coil so that half the tape is lapped over the preceding turn, thus placing two thicknesses of cotton tape on the coil. It is necessary that the tape be stretched very tightly when taping the coils in order to produce a solid dense coil

Fig. 91. Taping Coils with a Machine
Courtesy of the Reliance Electric and Engineering Company

free from air pockets. The machine shown in Fig. 91 winds the tape on with a higher and more uniform tension than can be obtained by hand. The taped coil is then heated in an oven for half an hour and, while hot, is dipped in amber-colored baking varnish as shown in Fig. 92 and allowed to remain for a few minutes. It is then placed in the oven with a temperature maintained at 200 to 220 degrees Fahrenheit until the coil is baked dry. This treatment is repeated two or more times until a glossy varnished surface is obtained on the coil. The coil is now ready for use on a 125-volt

Fig. 92. Dipping Coils in Insulating Compound
Courtesy of the Reliance Electric and Engineering Company

Fig. 93. Taping Field Coils
Courtesy of the Reliance Electric and Engineering Company

machine. For a 250-volt machine the whole bundle or coil is taped again with cotton tape, not overlapping, but for a 600-volt machine the cotton tape is half overlapped and the dipping and baking process is repeated again until a glossy surface is obtained. On 600-volt work a layer of half-overlapped linotape or empire cloth is often used under the first layer of cotton tape. The field coils of the motor are often dipped and baked in a manner similar to the armature coils, then taped as shown in Fig. 93, and given another dipping and baking after they are taped.

Insulating the Core. It is important to see that all the sharp burrs or fins on the laminations are removed with a file before beginning to insulate the core. One small steel sliver or burr can very easily cut through the insulation and ground the coil. This may cause the armature to burn out when placed in service. A

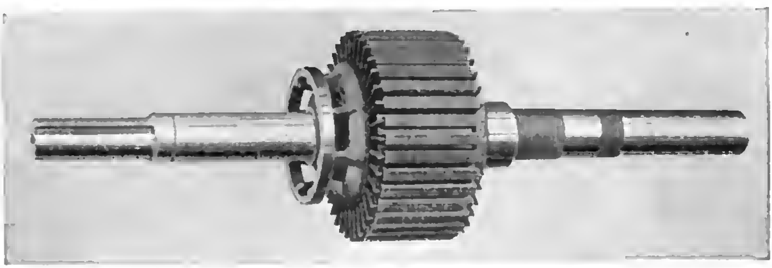


Fig. 94. Small Armature Core Ready for Winding
Courtesy of the Reliance Electric and Engineering Company

view of a core ready for winding is shown in Fig. 94. There is a supporting ring on the left-hand end plate of the core which should be insulated with wood, fiber, or tape. The diameter of this ring should be nearly the same as the bottom of the slots so the back end of the coil will extend out straight and rest on this ring. It is often necessary to build this ring up to the correct diameter with strips of fiber before binding them to the ring with tape. The method of performing this work is shown in Fig. 95.

After insulating the supporting ring the next operation is to insert the U-shaped slot insulation in all the slots, Fig. 96. The treated coils shown in Fig. 92 are used in winding the armature and, if they have been spread to the correct shape and pitch, they can be easily inserted in the slots. A paraffin-coated fish paper is often used as the slot insulation. This allows the coil to enter the slot

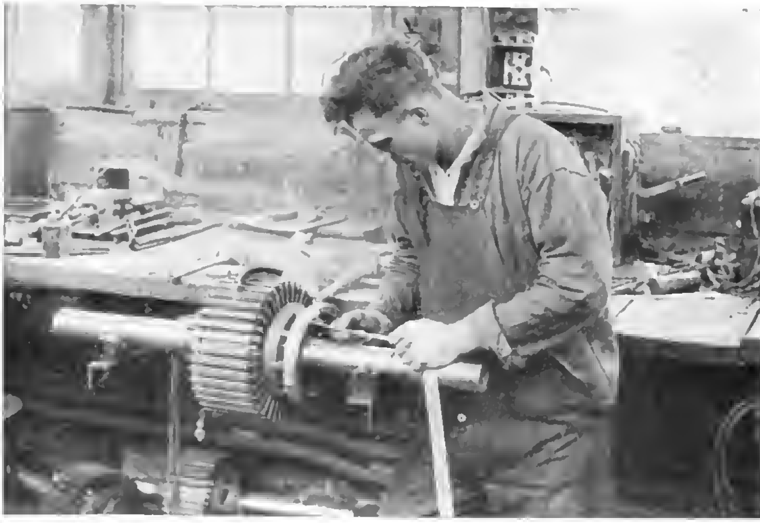


Fig. 95. Insulating the Supporting Ring at the Back End of the Armature
Courtesy of the Reliance Electric and Engineering Company

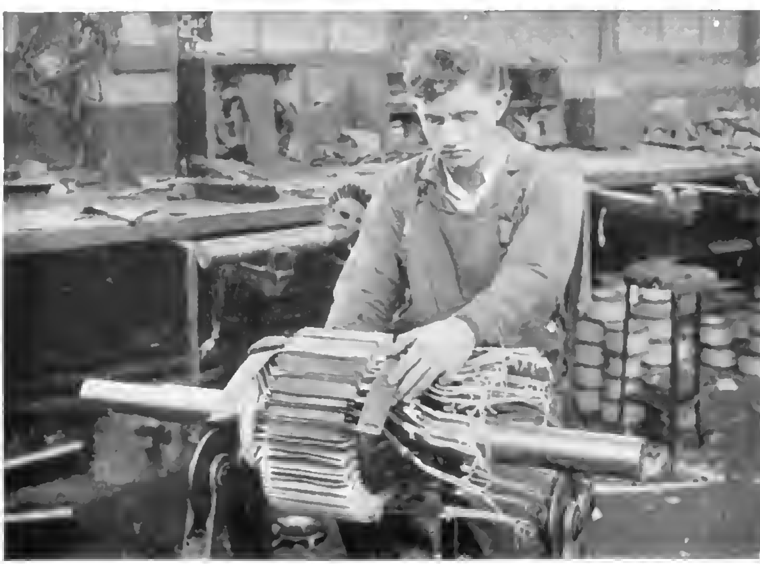


Fig. 96. Placing Coils in the Slots of the Armature Core
Courtesy of the Reliance Electric and Engineering Company

much easier than the ordinary fiber paper does. When paraffined paper is not used in the slots, the portion of the coil that enters the slot should be treated by rubbing the coil with a bar of paraffin. This will enable the coil to enter the slot much easier and is well worth the time spent in doing the work, especially when the coils are a very tight fit. It is also necessary to insert strips of fiber between the top and bottom sides of the coils on both the front and back ends of the winding which is outside the slots. These fiber strips are to prevent the top coil from pressing against and becoming short-circuited with the lower coils, due to the pressure from the banding wires which are above these points on the winding.

Winding the Armature. The coil is inserted in the slot so that one side will be in the bottom of the slot and the other side in the top of another slot. After inserting the first coil its span should be checked with the electrical data for that particular armature, because it frequently happens that the coils may have been spread for a different span than that called for and the error would not be discovered until the completed machine was placed on test. The next coil is inserted either to the right or the left of the slot in which the bottom side of the first coil was placed. This coil will always be placed so that the center of it will be over or above the first coil. The coils are all inserted in this manner until the winding is completed. It will be necessary to raise up out of the slot all the top coils that have not been placed on top of the bottom coils so that the bottom sides of the last coils can be inserted in the slots. It may be necessary to use a wooden or, better still, a rawhide mallet to drive the coils down in the slots. When a mallet is not available, a strip of hard fiber $\frac{1}{4}$ to $\frac{3}{8}$ inch thick and about 2 inches wide can be held on the coil while a hammer is used on the fiber to drive the coil into place. This will allow the coils to be driven into place without smashing or cutting the insulation. The slot insulation is folded over the top of the coils and any excess length is cut off, so that the slot wedge, or top stick, can be driven in under the teeth of the slot. The leads of all the coils should be connected together with a piece of fine, bare copper wire and the winding given the usual dielectric test in order to locate any defects or grounds which may exist in it. The top leads from the coils are all bent back so that they will point toward the pulley end of the

Fig. 97. Placing Upper Layer of Connections to the Commutator in Position
Courtesy of the Reliance Electric and Engineering Company

Fig. 98. Placing Insulation over the Lower Leads to the Commutator
Courtesy of the Reliance Electric and Engineering Company

shaft, and the bottom leads are pulled outward in an inverted cone shape to enable the commutator to be pressed into position on the shaft.

Connecting the Coils. The correct commutator bar to which the bottom lead of the coil is connected is located from the data as explained and illustrated in the preceding pages. The bottom leads of adjacent coils are connected to adjacent commutator bars until the bottom leads have been connected to all the bars. The lower leads are insulated from each other near the commutator by a cotton tape, about an inch wide, that is passed over one lead, under the next lead, over the next lead, etc., as is also done on the top leads, Fig. 97. This tape is shown lying loosely on the top leads that have been bent back over the core. A piece of heavy canvas is placed over the lower leads, Fig. 98, after they have been connected to the commutator bars. The canvas is secured in place with friction tape, which is represented by the black bands in Fig. 97.

The winder is now ready to connect the top leads or end connections to the commutator bars. A pair of test leads, with a lamp in series with one or both leads which are connected to the electric light circuit, is needed in order to find the two ends of the same coil. After locating the correct bar and connecting the first of the top leads to it, the lead for the adjacent coil is located with the test lamps and connected to the next commutator bar. This process is repeated until all the leads have been connected to the commutator. The excess part of the wires that extend through the tang or riser of the commutator bars is cut off, either with a wire cutter or chisel, so that a heavy soldering iron can be held up against the end of the wires or risers in order to heat them for soldering. In soldering the leads a half tin and half lead solder is used with solution of rosin in alcohol for a flux. In this operation care must be taken that the solder does not run down the back side of the commutator and bridge across from one bar to the next, causing that coil to be short-circuited. When soldering, it is a good plan to place the armature so that the front of the commutator will be much lower than the back. The solder will then run away from the back side of the commutator.

Dipping the Armature. The completed armature should be placed in the oven for from one to two hours in order to dry out

all moisture and, while hot, dipped in an insulating compound, Fig. 99. Care must be taken with large armatures when attaching the clamp to the shaft to prevent the shaft from becoming dented at the portion which fits in the bearing. In order to avoid this trouble a split steel sleeve, having an inside diameter the same as the shaft, should be provided and placed inside the clamp, so that the pressure from the clamp will be over a considerable area. The bearing portion of the shaft is finished to within a half thousandth

Fig. 99. Dipping Completed Winding in Insulating Compound
Courtesy of the Reliance Electric and Engineering Company

of an inch (0.0005 inch), and any nicks or flat spots will cause the bearings to overheat.

Banding the Armature. A band of high-grade steel piano wire is wound on a strip of leatheroid that is placed around the armature and over the coils about half an inch to two inches from the edge of the core in order to prevent centrifugal force from throwing the coils outward when running at high speed. This is done either before or after the armature has been dipped and baked. It is best to do this work while the armature windings are hot, because the insulation shrinks when heated, is more flexible, and can be pulled down tightly much easier than when cold. When the first wire of the band is wound on the armature, small tin clips should

be inserted under the wire; and when the required number of turns has been wound on the armature, the ends of these clips can be turned up over the wires in order to hold them tightly side by side. These clips are soldered over with a tin solder and a thin coat of solder is run over the whole band to hold the wires together.

The completed armature is then placed in a lathe and a very light cut is taken over the face and side of the tang or riser of the commutator to make it perfectly true. If a commutator is eccentric even five thousandths of an inch (0.005 inch), it will push the brushes away from the commutator this much when the machine

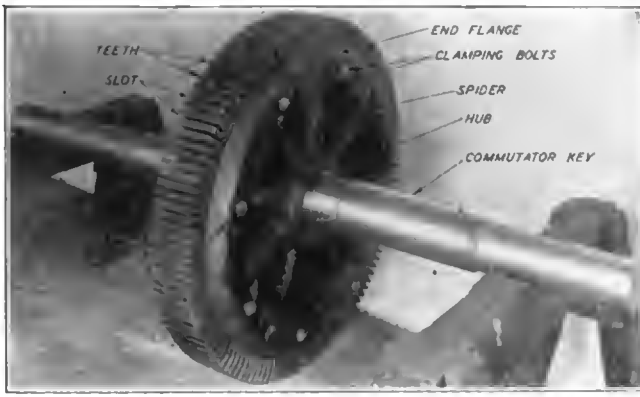


Fig. 100. Rotor Assembly for a 6-Volt 7500-Ampere Generator
Courtesy of The Ideal Electric and Mfg. Co., Mansfield, Ohio

is running. Instead of being conducted from the commutator to the brush the current must pass through this much of a gap, which will cause a slight arc and sparking. This will cause the commutator to operate at a higher temperature than otherwise.

WINDING A LOW-VOLTAGE ARMATURE

The winding of a low-voltage generator which is used for battery charging and electroplating is very similar to that of a medium-sized armature. The main difference is that in winding the low-voltage armatures fewer turns of wire are made per coil, and the size of wire used in the windings is larger. Often, in order to obtain the required cross-sectional area of the conductor, several wires are connected in

parallel. In larger armatures, small copper bars bent to shape and insulated with tape are used for the coils.

On low-voltage generators used in electroplating work, the rotor core is usually much shorter in length and has a larger number of slots than the 125 or 250-volt machines. The slots are usually narrow and very deep as shown in Fig. 100. The laminations are assembled on the spider and keyed to it, then they are clamped tightly together by bolts that pass through the end flanges and rotor spider. The rotor spider is pressed on the shaft and secured to the hub by a key.

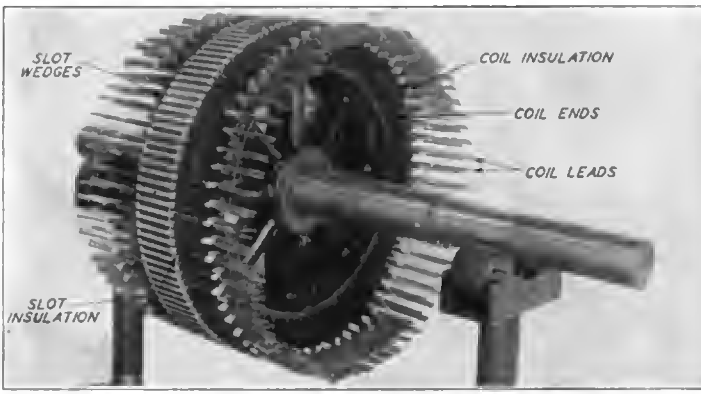


Fig. 101. Insertion of Armature Coils in Slots Has Been Completed
Courtesy of The Ideal Electric and Mfg. Co., Mansfield, Ohio

The particular rotor in Fig. 100 is used on a 6-volt generator that will produce 7500 amperes of current for use in electroplating work.

The armature coils are of the involute type and pressed to shape in a forming die or jig. The coils are insulated with linen tape, then dipped in insulating varnish and baked dry. Each slot is insulated with horn fiber and paper insulation, Fig. 101, before the coil is inserted. After the coil is put in place, the paper insulation is folded over and a hard fiber top stick or wedge is driven into the keyway or groove in the top of the slot. These wedges hold the coils in place. The operation of inserting the coils and wedges in the slots has been completed in Fig. 101.

There are two sets of windings, and a commutator is to be placed on each end of the armature in Fig. 101. Each coil in this particular

armature consists of three square wires, probably some size between No. 10 and No. 6, connected in parallel. There are two *coil sides* (one side of each of two coils) placed in each slot. The coils in the odd-numbered slots are connected to one commutator and the coils in the even-numbered slots, to the other commutator. There are about 126 slots in the core and 126 armature coils.

One of the assembled commutators, Fig. 102, for the above armature contains 63 bars and 63 risers. In large machines equalizers

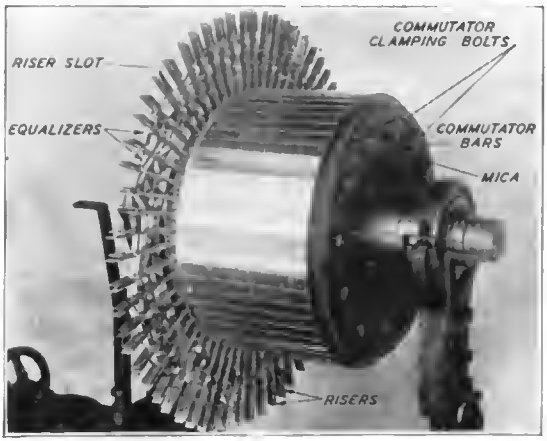


Fig. 102. Commutator Assembly Ready for Test on Dynamic Balancing Machine
Courtesy of The Ideal Electric and Mfg. Co., Mansfield, Ohio

are used to join together commutator bars that have the same voltage. The number of commutator bars joined together is the same as the number of pairs of poles or the number of sets of positive brushes. The armature shown in Fig. 101 is for a 14-pole machine (7 pairs) which will have 7 sets of positive brushes. The number of commutator bars in Fig. 102 from one positive brush to the next is ($63 \div 7$) 9. Therefore, every ninth commutator bar is joined together. Thus bars 1, 10, 19, 28, 37, 46, and 55 are joined together and form one equalizer ring. Then bars 2, 11, 20, 29, 38, 47, and 56 are joined together and form the second equalizer ring.

There are as many equalizer rings as there are commutator bars between positive sets of brushes. The purpose of these rings is to

equalize any slight difference in voltage produced by one set of armature conductors under one pair of poles as compared to those under some of the other sets of poles, since it is impossible to have all magnetic fields of the same exact magnetic strength. The current flows through these equalizer rings instead of flowing from one com-

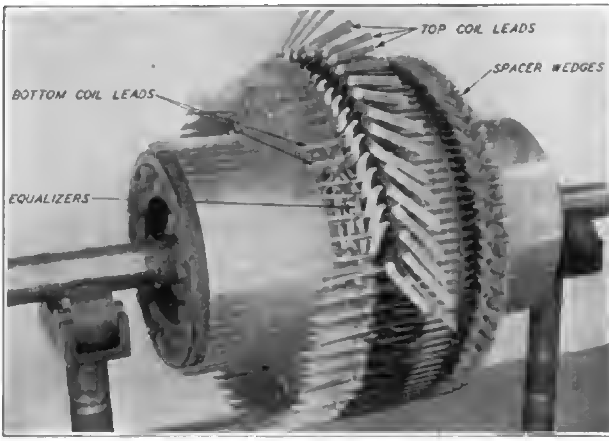


Fig. 103. Connecting Coils to Commutator
Courtesy of The Ideal Electric and Mfg. Co., Mansfield, Ohio

mutator bar through the positive brush to the brush holder frame and then to another positive brush and commutator bar. The resistance of the parallel path through the brushes is many times that through the equalizer ring, and so these equalizers reduce unnecessary heating of the commutator bars and brushes, thus improving the operation of the generator.

The assembled commutators are fastened to the shaft with a key. The ends of the armature coils in the bottom of the slots are bent to secure the proper "throw" and then connected to the bottom of the groove in the riser as shown in the top part of Fig. 103. All the bottom coil leads are bent in the same manner and connected to the risers. Then the top coil leads are bent in the opposite direction from that of the bottom leads and connected to the top of the groove in the riser. The connections of the coil leads to the risers have been completed for the right-hand commutator in Fig. 103.

A wood or fiber spacer wedge is inserted between the commutator

risers in order to hold the sides of the riser slot tightly against the coil leads when they are being soldered. After the soldering work is completed, the wedges are removed.

The next operation on the armature is to put the band wires in place, then the armature windings and risers are painted with a

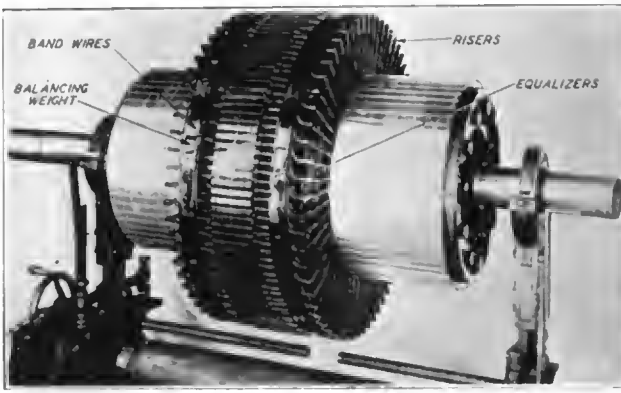
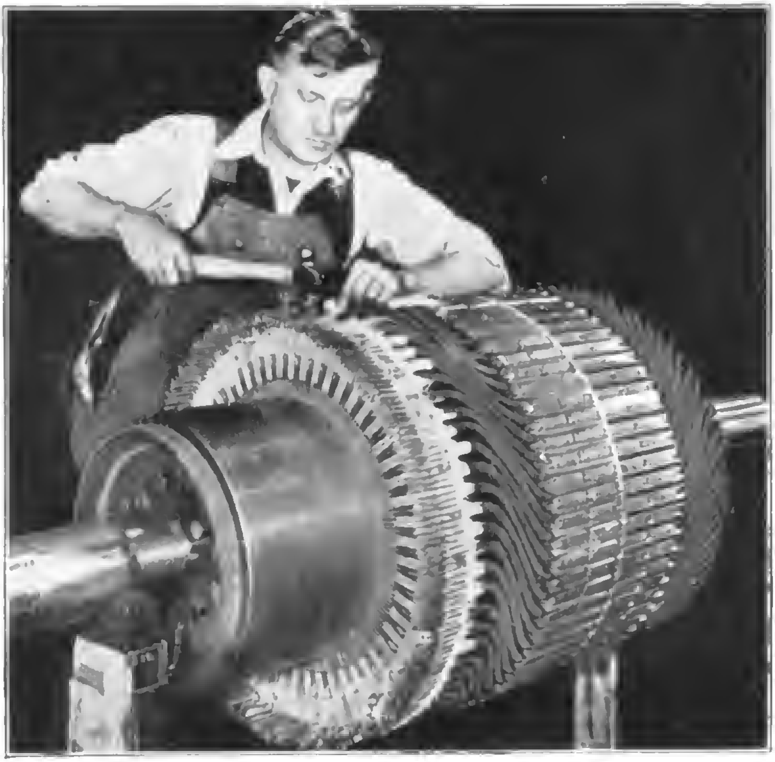


Fig. 104. Completed Armature Ready for Test on Dynamic Balancing Machine
Courtesy of The Ideal Electric and Mfg. Co., Mansfield, Ohio

good air-drying insulating varnish. The completed armature is next placed on a dynamic balancing machine, Fig. 104, where it is run at speeds up to 1½ times the normal operating speed. Any tendency to vibrate due to more weight on one side of the shaft than on the other is corrected by adding more weight, usually solder on the band wires, to the lighter side.



CONNECTING COIL LEADS TO COMMUTATOR RISERS
Courtesy of Carnegie-Illinois Steel Corporation, Pittsburgh, Pa.

REPAIRING DIRECT-CURRENT MOTORS AND GENERATORS

REPAIRING MECHANICAL PARTS

Locating Defects. The general nature of the defect in a motor or generator is usually determined before the motor is sent to the repair shop, or repair department. In those cases where the nature of the defect is not known to the repair shop or to the one doing the work, the motor should be connected to a source of supply the same as that given on the nameplate. In many cases the nameplate will be missing, and therefore the only thing to do is to connect it to the lowest voltage circuit available. The usual voltages for motors used for industrial power work is 110 to 220. When the size of the motor is such that the output may be two horsepower or less, it may be used either on 110 or 220 volts; while if the motor is larger, it undoubtedly will be operated on 220 volts. The field winding of industrial power motors is either shunt or compound, except crane, hoisting, mining, and railway motors, which are nearly always series motors. Motors that are used on this class of service can be easily identified by their appearance. When testing out the motor a small fuse should be placed in the line circuit, and when possible a continuous duty rheostat, with sufficient resistance to limit the starting current to a safe value, should be inserted in series with the armature. This resistance can be decreased as the motor speeds up until it is running at normal speed. With the motor running at normal speed it should be examined for sparking at the commutator, for end thrust against either one of the bearings, and for lubrication of the bearings by the oil rings. When there is sparking at the commutator, the defect can be located by using the methods given in section on "Locating Motor and Generator Troubles." The end thrust against one of the bearing sleeves can be located by using a pointed stick to push the armature endwise in the bearings. It should be possible to push the armature endwise from $\frac{1}{64}$ to $\frac{3}{8}$ of an inch at each end. If it is impossible to push

the armature endwise in its bearings while it is running, the armature is pushing against the bearing on the opposite end. This end thrust is due to the fact that the center of the armature core is not in line with center of the pole pieces. Where this thrust is excessive, it may be due to the fact that the pulley end of the machine was placed on the wrong side of the frame. This condition can easily occur when the poles are located near the center of the frame and the brush holders are supported from the bearing bracket. This can be remedied by removing the armature and bearing brackets and turning the frame end for end, or by removing the pole pieces, when they are bolted against the frame, and turning them end for end.

Tearing Down the Machine. It is always best to mark the parts that fit on one another before removing them from the machine. The brush rocker arm is usually fastened in place on motors or generators that have interpoles so that it cannot be shifted from its correct position. If it should be necessary to remove the brush rocker arm, its location should be marked by means of a center punch or small narrow chisel so that it can be replaced in the same position as originally. When the brush rocker arm is supported from the bearing bracket, it is seldom necessary to remove it in taking the machine apart. It is nearly always necessary to remove the brush yoke when it is supported from the frame and before removing it a chisel mark should be made on the frame and one directly opposite it on the brush yoke.

In removing field coils and pole pieces the numbers 1, 2, 3, and 4, should be stamped on the commutator side of the pole and also on that edge of the frame in order that they may be returned to the proper place when reassembling the machine. The reason for this is because sometimes the manufacturers do not make the poles symmetrical or, in order to make the machine meet certain requirements, one side of the pole tips may be cut off or made to have a greater air gap on one side than on the other. It is also necessary to watch and see that any shims or thin pieces of sheet steel that are between the pole and frame are securely attached to the pole in order to prevent them from being lost. The cap screws that are used to hold the pole pieces to the frame should be inserted in the tapped hole in the pole and they should be examined to see if they will fit properly. A half-inch cap screw with 13 threads per inch

is used on a large number of machines of medium size for holding the pole pieces in position, and often a mistake may be made and a cap screw with 12 threads per inch will be used which will give trouble, because it will not fit properly. The hole in the pole piece may not be drilled deep enough or threaded clear to the bottom, and this will not allow the cap screw to enter far enough to hold the pole firmly against the frame, although the cap screw has been tightened as tight as the rest with a large wrench. If this condition is not remedied before the motor is connected to the line, there will be trouble due to the pole piece being attracted toward the armature and possibly coming in contact with it while it was running, which would wreck the machine.

Worn Sleeve Bearings. A worn bearing can be discovered by taking hold of the end of the shaft and lifting it vertically and sideways and noting if there is any play between the shaft and bearing. The bearing on the pulley end of a motor or generator usually wears more than the one on the front or commutator end of the machine. The action of the shaft and belt on the pulley is similar to a lever. The force on the bearing on the pulley end multiplied by the distance from its center to the center line of the belt must equal the force on the bearing on the commutator end times the distance from the center of its bearing to the center line of the belt. The distance from the bearing on the commutator end to the belt is several times the distance the other bearing is from the belt; therefore the force on the pulley end bearing must be several times that on the other bearing.

Removing Sleeve Bearings. It is necessary to use care when attempting to remove the bearings from the bearing bracket, otherwise the bracket will be damaged so badly that it will be necessary to replace it. Each manufacturer almost invariably uses a different method of preventing the bearing sleeve from turning in the bracket and for retaining the oil ring in its proper place. In Fig. 1 the bearing sleeve *A* is pressed up against the shoulder of the bearing bracket at *B* and the set screw *P* prevents the sleeve from working loose in the bracket and revolving with the shaft. It is necessary to remove this set screw before attempting to remove the bearing from the bracket; otherwise the set screw *P* will be broken or, as is usually the case, the part of the hub of the bearing bracket shown

at X will be broken off. The bearing bracket is usually made of cast iron, and it is impossible to repair it, thus making it necessary to secure a new one from the manufacturer. On some machines there is a slot milled in the bearing sleeve from the set screw P to the right hand of the sleeve. In this case the set screw will have

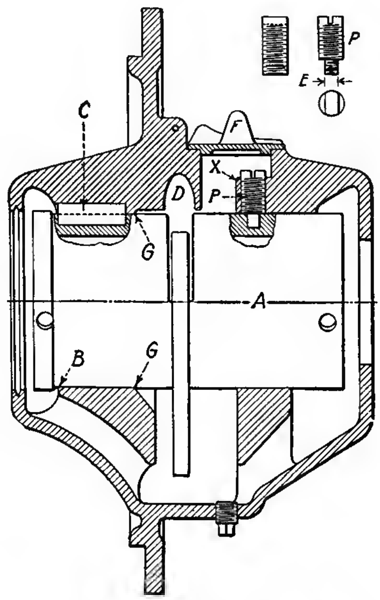


Fig. 1. Method of Locking Bearing in the Bracket

one end milled off, as shown in the upper right corner of Fig. 1. The thickness of the flat portion of the set screw E will be about a $\frac{1}{64}$ of an inch less than the slot. With this type of locking device it is impossible to insert or remove the set screw while the bearing is in place.

Another method of holding the bearing in place is by the use of a small key, as shown in Fig. 1 at C. In Fig. 2 a lug is cast on the bearing sleeve which, when forced into position in the bearing bracket, is located between two lugs cast on the hub of the bracket. The disadvantage of this type of bearing sleeve is that a special pattern must be used and it is harder to obtain as good castings and bearings as when the sleeve is made from a hollow cylinder, Fig. 1. When the diameter of the shaft exceeds two or three inches, a babbitted

bearing is often used. There is usually a cast or malleable iron sleeve used to transmit the strain from the babbitt metal to the bearing bracket and also act as the outside of the mold when the molten babbitt metal is being poured into place. A lug may be cast on the iron sleeve to prevent the bearing from turning, or a three-eighths

Fig. 2. A Phosphor Bronze Bearing
Courtesy of the Louis Allis Company

of an inch hole can be drilled nearly through the iron sleeve and a short steel driven into this hole.

It is also necessary to see that the oil ring is moved so that it will not interfere with the bearing sleeve when it is being removed. The bearing bracket shown in Fig. 1 should be turned upside down so that the oil ring will drop into the cavity or groove *D* while the sleeve is being removed. If this precaution is not taken and the oil ring is left in the position shown, the sides of the ring will catch on the edges of the hub at *G*, thus damaging itself and also the bearing. The oil ring is often retained in the slot by means of a wire that is run through a small hole which is drilled through the upper part of the sleeve and parallel to the center line of the shaft. Another method sometimes used is to attach a small metal clip to the top of the sleeve with a small screw after the bearing is in place. This clip is inserted through the top oil cover *F* in Fig. 1 and when in place will extend over the top of the oil ring groove and keep the oil ring in place.

Replacing Sleeve Bearings. When placing new bearing sleeves in the bearing bracket care should be taken to see that any slots, lugs, and keyways are in line with the proper set screws and grooves

before starting to press them in place. The outside diameter of the sleeve is usually from one to five thousandths of an inch larger than the hole in the hub so they will be a light press fit. When possible the bearings should be pushed into place with a small hand press or by a heavy lever. When these methods cannot be used and it is necessary to drive the bearing into place with a hammer, a short length of round brass or copper bar the same size as the largest diameter of the sleeve should be held against the sleeve. The hammer should be used on the end of the bar in order to prevent marring or damaging the end of the bearing sleeve.

Assembling Ball Bearings. The use of ball bearings on electric motors and generators is becoming greater each year due to the fact

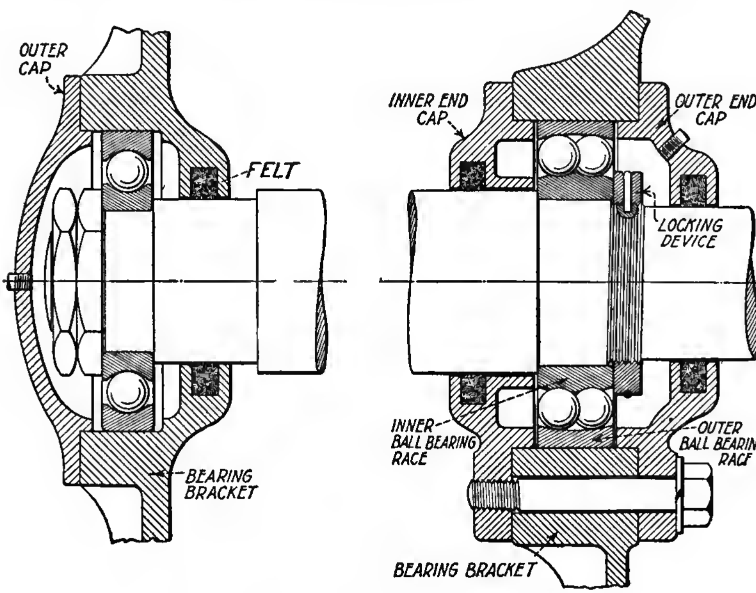


Fig. 3. Method of Mounting Ball Bearings

that they will operate for long periods of time without attention. This does not mean that they will operate forever without any attention, but where the motor having sleeve bearings has to be given attention once a week, the motor with ball bearings will only have to be looked at once a month. This change is more noticeable when the motor is installed in a very dusty place as it may then be necessary to clean the oil wells and renew the oil every week. The

method of mounting the ball bearings in the housing of the bearing brackets is shown in Fig. 3. It will be seen that the housing caps on the right hand or pulley end bracket must be removed before the bearing bracket can be removed from the frame. This type of construction is used by the majority of manufacturers, although there are some that do not use the inner housing cap, but machine the housing in the bearing bracket as is the case in the left-hand bearing of this figure. It is more difficult to dismantle and assemble a machine where this type of construction is used, because both ball bearings must be removed before the brackets can be removed.

The method of assembling the bearings on the shaft is shown in Fig. 4. It will be seen that a smaller ball bearing is used on the

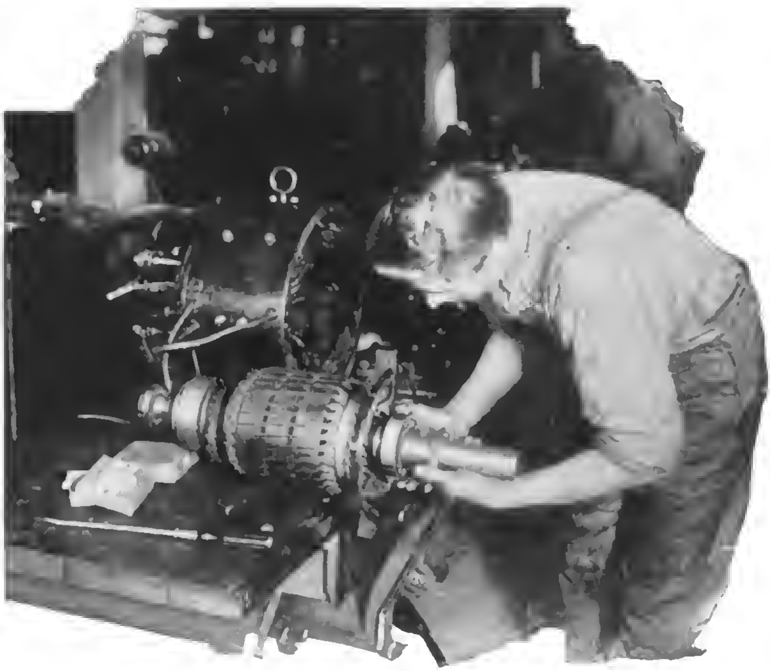


Fig. 4. Assembling Ball Bearings on Shaft
Courtesy of the SKF Industries

commutator end of this motor than on tne pulley end. The shaft in this particular case is ground a few thousands smaller than the inside diameter of the ball bearing so that it can be pushed into place and then locked by the clamping ring that the assembler has

in his left hand. The shaft is usually made so that the bearing is a light press or drive fit on it, while the inside of the housing is made so that there is a light sucking fit between it and the outer race of

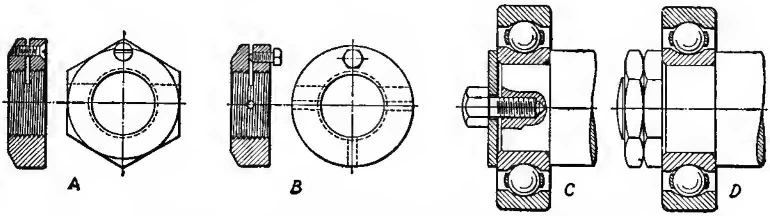


Fig. 5. Method of Locking Ball Bearings on the Shaft

the bearing. The inner race is locked on the shaft and revolves with it by means of a narrow nut which is locked on the shaft by means of a wire spring, or two nuts as shown in Fig. 3. In Fig. 5 some of the other methods used in locking the inner race on the shaft are shown.

In handling ball bearings care must be taken to see that no grit or dirt is allowed to get in the raceways. After being removed from

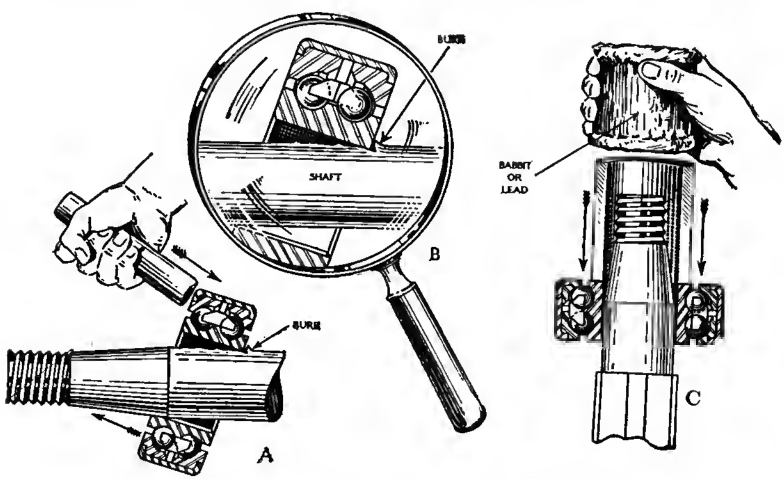


Fig. 6. Wrong and Right Methods of Installing Bearing on Shaft
Courtesy of New Departure Manufacturing Company

the shaft they should be cleaned in gasoline or kerosene and then given a spin to see if they work freely and if they can be used again in this motor. When they are to be used again, they should be

lubricated with vaseline or ball-bearing grease and revolved several times to work the lubricant into all parts of the bearing and then wrapped in clean brown or white paper until ready to be replaced on the shaft. The best method of placing bearings on a shaft is to use a small arbor or hand press and push them into position. When this method cannot be used, secure a copper or brass tube that will slip over the shaft, as shown at *C*, Fig. 6, and the bearing can be forced into place by hammering the tube. Do not under any circumstances strike the outer race with a hammer or rawhide mallet or any piece of metal as this will only cause the inner race to dig in the shaft, as shown at *A* and *B*, Fig. 6. The bearing may also be forced into position by holding a piece of hardwood against the inner race and striking the wood with a hammer, as shown in Fig. 7.

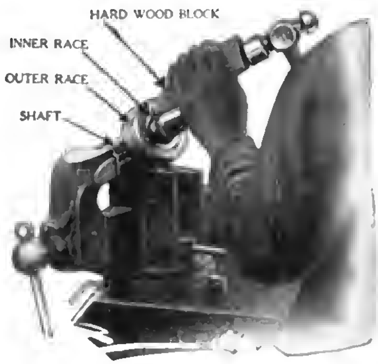


Fig. 7. Assembling Bearings with Aid of Wood Block
Courtesy of New Departure Manufacturing Company

Lubrication of Ball Bearings. The ball bearings used on electric motors may be lubricated either with oil or a good grade of ball bearing grease or petroleum lubricant. When the manufacturer has provided an oil cup, a good grade of mineral oil should be added when necessary. It is advisable to use oil instead of grease when possible to do so, especially on high speed motors. When the manufacturer has not made any provision for supplying oil or grease, the outer housing caps should be removed from both bearings about every six months and the old grease washed out with clean gasoline or kerosene and the bearing inspected to see that it is operating properly. The bearings should then be packed with a grease, made

especially for ball bearing work, using care to see that the bearing space is filled completely. When filling the bearing box, the motor should be revolved slowly in order to force the grease into the other side of the bearing. The ordinary vaseline or petroleum jelly can be used when the ideal grease for ball bearings cannot be obtained. When the caps of the bearing housing of the motor are fitted with pipe plugs, a grease gun, such as is used for lubricating automobiles, can be used to force new grease into the bearing housing. The old grease will be forced out around the shaft, where it can be wiped off with rags. The armature of the motor should be revolved while the grease is being forced into place in order that all parts of the bearing will be filled. The motor should then be run for several minutes in order to force the old surplus grease out around the shaft, where it can be wiped off.

REPAIRING FIELD COILS

Grounded Field Coils. The field coils should be tested for "grounds" by applying twice normal voltage between the windings of the fields and the frame of the machine. This can be done with a testing transformer or by securing the higher voltage from some other circuit. When there is no high voltage available, the insulation can be tested by connecting a voltmeter in series with the field winding connected to one side of the line while the other side of the line is attached to the frame of the machine. If the voltmeter should indicate nearly the same voltage as when attached to the line, it indicates that the field coils are making contact with the frame. Another method is to take a pair of test leads which have a small lamp in series with each side of the line and attach one lead to the field windings and the other lead to the frame. Then if there is very much current flowing through the circuit the lamps will burn dimly or brightly. While the test leads are attached to the field and frame, each coil should be tried to see if it can be moved on the pole piece and thus discover where the defect exists. It may be necessary to remove the coils from the pole pieces or open the connections in the leads between the coils in order to locate the defective one. When the defective field coil is wound on a metal spool or bobbin, it is necessary to rewind the coil. Where the "ground" is due to defective insulation between the field windings, it can often

be repaired by inserting a piece of horn fiber between the coil and the frame, or by retaping the coil.

Short or Open Circuited Field. The shunt and series fields should be connected to a circuit that will pass the normal current through their windings. The voltage drop between the two terminals of each coil should be obtained with a voltmeter. The readings for all coils of the shunt or the series winding should be the same. The coil with a low reading would indicate either that it did not contain as many turns of wire as the others, a larger size of wire was used, or some of its turns were "shorted." The defective coil should be removed and tested for short circuited turns on the E-shape coil tester shown in Fig. 8. The top yoke of the tester is easily removed

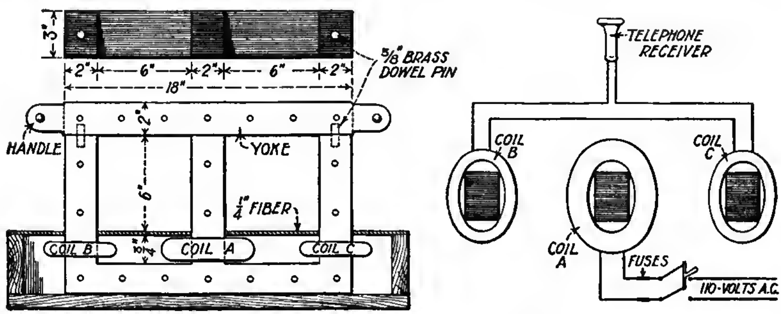


Fig. 8. Device for Testing Field Coils

by means of the handles so that the coil to be tested can be slipped over one of the outer legs, and the yoke is replaced. The two brass dowell pins make it possible to place the yoke in the proper position. The coil *A* on the center leg is composed of 250 turns of No. 12 B & S gage double cotton covered wire and the coils *B* and *C* each have 100 turns of No. 30 enamel single cotton covered wire. The coils *B* and *C* are connected so that the voltage induced in them will buck each other and normally there will be a very small current if any flowing through the telephone receiver, which will only produce a slight hum. When a coil that has a short-circuited turn in it is placed over the outer core or leg and the yoke is replaced, a magnetic unbalance will occur and the telephone receiver will give off a louder sound or noise than otherwise. A push button switch should be located in the wooden base so that the current can be turned on only for a few moments at a time. The *A* coil should be

connected to a 110-volt alternating-current circuit, although where direct current is the only kind available, a large door bell can be connected in series with one of the line leads and produce an interrupted current. The door bell should be located far enough away from the testing outfit that it will not interfere with the sound given off by the telephone receiver.

An open circuit in the field coil will not allow any current to pass through that circuit. It can be located by momentarily touching a copper wire jumper to the two terminals of each of the coils until the defective one is located. When the shunt field is wound with small wire, the defect may be where the terminal is attached to the coil, and the connection can be resoldered. When the open circuit is inside the winding of the coil, it is necessary to rewind the coils with new insulated wire.

Rewinding Field Coil. When it is necessary to wind a field coil to replace a defective one, the insulation should be cut so that

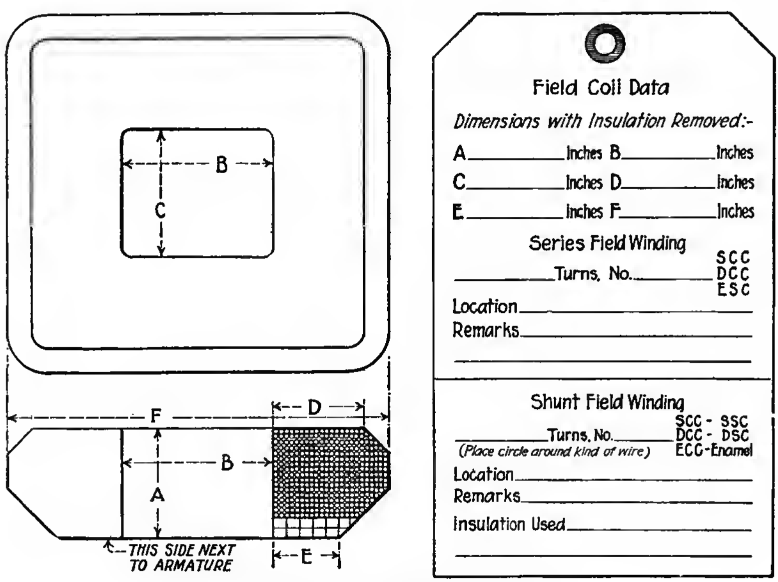


Fig. 9. Recording Field Coil Data

the dimensions shown in Fig. 9 can be obtained. These dimensions are taken so the person winding the coil will have a guide and they must not be exceeded, or the completed coil will not fit in the machine.

A block of wood having the thickness of the *A* dimension and a length and width of the *B* and *C* dimensions is obtained. When a machine for winding field coils is available, a hole is drilled in the center of the *B* and *C* dimensions and the block is clamped between the two face plates of the machine. If such a machine is not available, the sides for the former can be made from $\frac{3}{4}$ inch or 1 inch boards. The dimensions of one board will be twice the *D* dimensions added to both *B* and *C*, while the other one will be twice the *E* dimension added to *B* and *C* dimensions. One board is nailed or fastened on one side of the block and the other one on the other side. The center of the coil former is located, and it is clamped between the center pins on a lathe; one side is fastened to the face plate so it will revolve when driven by the lathe. The lathe is placed in back gear or slow speed in order that the winder can control the wire while it is being wound on the former. A strip of heavy paper the width of the former is cut and wound around it, and six or eight strips of cotton tape about a foot long are inserted under this band and their ends are fastened on the outside of the sides of the coil former. These strips of tape are tied around the coil when the winding is completed in order to hold it in place when the former is removed.

It is best to use rubber covered wire of a size smaller than that used in winding the coil, for the external leads from the coil. When the wire used on the fields coils is smaller than No. 17 B & S Gage, number 18 rubber covered lamp cord should be used. The length of the leads should be such that they can make one turn around the coil or former and should be carefully soldered to the wire used in winding the coil, care being taken to obtain a good connection. When the wire for winding the fields is larger than number 20, it should be wound in layers, otherwise there will be difficulty in winding the correct number of turns in the space allowed. When the coil has been wound so that the last layer is level with the top of the former, that side of the coil should be tapered by placing one less turn on that side in each layer; then when the top of the other side of the former is reached, it should be tapered in like manner. As soon as the correct number of turns have been wound on the coil and the external leads connected to it, the ends of the cotton tape should be drawn over the coil and tied tightly. The series

field winding is sometimes wound next the pole piece and under the shunt winding, on the top or along side of the shunt winding and near the armature side of the coil, as shown in Fig. 9. When the series winding is on the inside or along side of the shunt, its winding should be wound in place before starting the shunt winding. With this winding on top of the shunt, it should be wound in position before the coil is removed from the former. The completed field coil is dipped in insulating compound and baked and then the required layers of insulating tape wrapped in place.

Assembling Field Coils. When the new field coils are being baked, the old coils should be dipped in the insulating varnish or else painted with a coat of paint that will match the new coil. All dirt and oil should be removed from the old coils before painting, and where this cannot be done the outer layer of old tape should be removed and new tape applied. This extra work, while it may not be necessary, is well worth the cost, because it will give the motor the appearance of a new machine, and the customer will be well satisfied with the work. When all the field coils have been removed from the machine, and no record has been made so as to aid in identifying their location, it is best to lay them out on a table with the side that goes toward the armature upward and make temporary connections between coils in the same manner as when they are connected in the machine. The coils will appear similar to *A*, Fig. 10. The coil marked *S1* is the one on the lower left-hand pole piece when looking from the commutator end toward the driven or pulley end. This is the same as cutting the machine through the vertical center line and laying the right-hand half on the right side and the left-hand half on the left side. Thus poles numbered *1* and *4* have the same position as when they are in the machines. The interpoles or commutating poles are numbered in similar manner, and number *1* is between No. 1 and No. 2 main pole as will be seen at *D*, Fig. 10. The letters *I* and *O* indicate which is the outer and which is the inner turns of the coil. In connecting the coils together it will be seen that the *O* end of one coil is connected to the *O* of the next coil, and the *I* ends in like manner.

At *B*, Fig. 10, the leads from two of the coils have been crossed inside the taping of the coil so that the crossing of the leads as shown at *A*, Fig. 10, will be eliminated. In all these sketches the *I*

lead of the left-hand and the right-hand coils while connected in the machine are not shown connected here in order to convey the manner of making the connection. In these figures the left-hand arrow con-

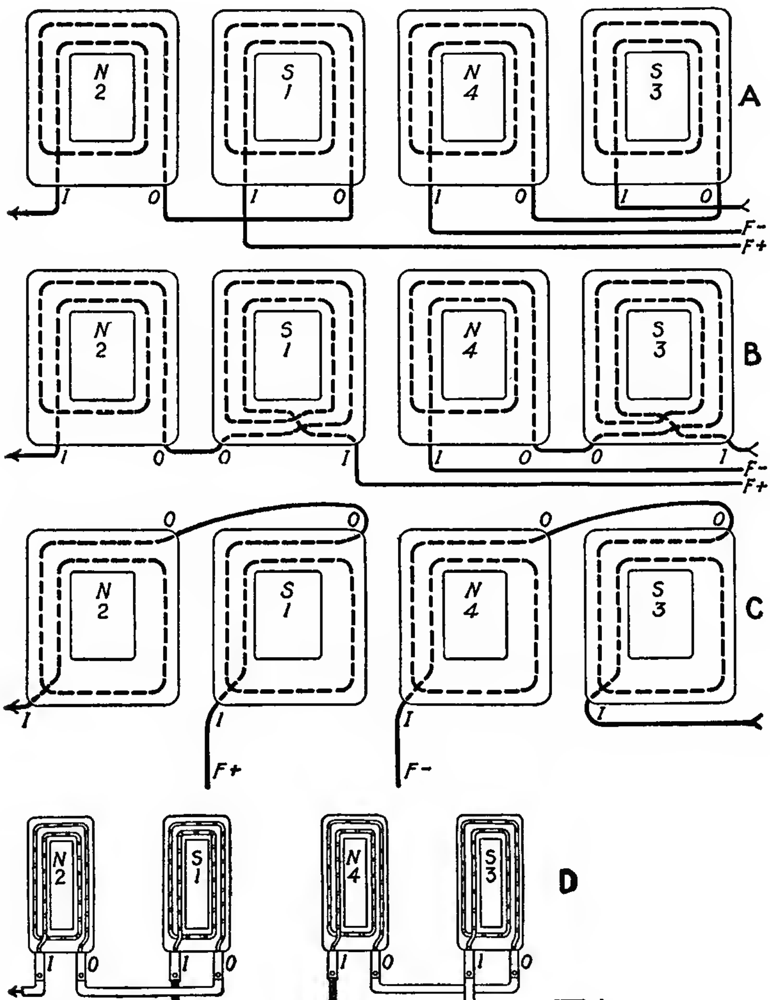


Fig. 10. Method of Connecting Field Coils in a Machine

nects with the V-shaped end of the lead on the right. In some machines the space for the end connections is very small, and then part of the coils are connected together on the front or commutator

end and part are connected on the rear end of the pole pieces, as shown at *C*, Fig. 10. The interpole, or commutating pole, winding is usually wound out of strap copper in the larger sizes and the connection between coils is usually made with this material, which is then insulated with cotton tape and insulating varnish. The strap copper connections occupy less space than cables and can be bent to any desired shape. The usual method of connecting the interpoles is shown at *D*, Fig. 10.

The interpole of a motor is connected so that it has the same magnetic polarity as the pole tip nearest it in a direction back against the direction of rotation. On a generator the commutating pole has the same magnetic polarity as a pole tip nearest it in a direction forward with the rotation. Thus the polarity of the main and commutating poles shown at *C* and *D*, Fig. 10, is for a motor running in a clockwise direction or a generator running in a counterclockwise direction.

A motor may run in the opposite direction from that for which the polarity of the poles were figured. In this case its direction should be reversed by reversing the leads connected to the brush holders, which will make the direction of rotation and polarity correct. If a generator should give the opposite polarity from that originally calculated and thus reverse the magnetic polarity of the interpoles, it can be corrected by interchanging or reversing the leads at the brush holders. When it is desired to reverse the direction of rotation of a machine, the leads from the armature and interpole should be interchanged where they are connected to the line.

REPAIRING ARMATURE

Determining Extent of Repairs. The first thing to do with an armature as soon as it has been removed from the machine is to locate the defects. When the machine appears to be ten to fifteen years old and there are several defects—such as open circuits in the coils, coils grounded, and commutator has deep grooves or ridges—it is best to rewind the armature and not spend any time in attempting to repair the defects. The portion of the shaft that fits in the bearings will undoubtedly be worn and grooved due to the wear from the oil ring and will have to be repaired. It will be well to consider whether the machine is worth the cost of repairs, which is

always higher on the older types of machines, or would it be cheaper to scrap the old machine and apply its value towards the purchase of a modern machine. The life of an electric motor or generator is from ten to twenty years and the depreciation is figured at 8 to 12 per cent of its original cost each year. Thus if the cost of repairs plus its value as scrap is more than one-third of the cost of a new machine of the same capacity, it would be cheaper to purchase the new machine. The new machine will undoubtedly have a higher efficiency, which will reduce the operating cost several per cent.

When the windings appear to be in good condition and the defects appear to be confined to one or two coils, the armature can then be repaired without rewinding. Should the defects be such that it is necessary to replace several coils, it is best to rewind the armature, because the insulation on the coils is very brittle and due to handling they will have to be reinsulated. One or two coils in an armature that may have a short or open circuit in them can be easily cut out, and the machine will operate without them. The methods used in locating defects are the same as those described in the section on "Winding Armatures."

Locating Defective Coils. An open circuit in an armature of a machine is usually first indicated by sparking at the commutator. A vicious greenish-purple spark will usually appear at each brush as the open-circuited coil passes from one pole to the next one. The commutator bars that are connected to this coil will be rough and burned and the mica between them will be burned out to a considerable depth. With a wave instead of a lap winding it is more difficult to locate the defect because in a four-pole machine there may be two bars that are blackened or the mica may be burned out between commutator bars diametrically opposite each other. The method for cutting out an open coil is shown in Fig. 11. In this illustration coil *3* is the defective one. When the defect is due to an open circuit, the commutator bars *3* and *4* can be connected together by soldering across the riser or tang of these bars. It is better however to remove the leads *A* and *B* from bars *3* and *4* and connect a wire jumper across the two bars. When there is a short circuit in the coil and there is more than one turn in each coil, the wires should be cut as shown at *C*. The ends of the leads at *A*, *B*, and *C* should be insulated with tape and bound to the other coils so

that they will not be thrown outward when the armature is revolving and strike other coils and wear the insulation off them. This dead

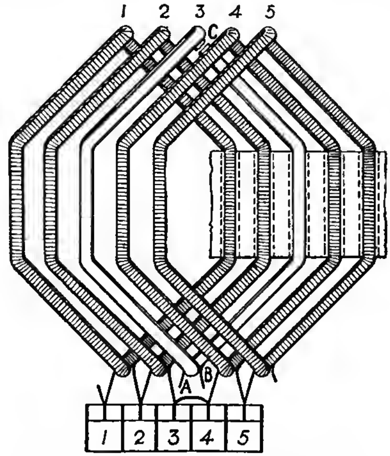


Fig. 11. Method of Cutting Out Coils in a Lap Winding

coil will have voltage generated in it the same as the others, but no current can flow because the circuit is open.

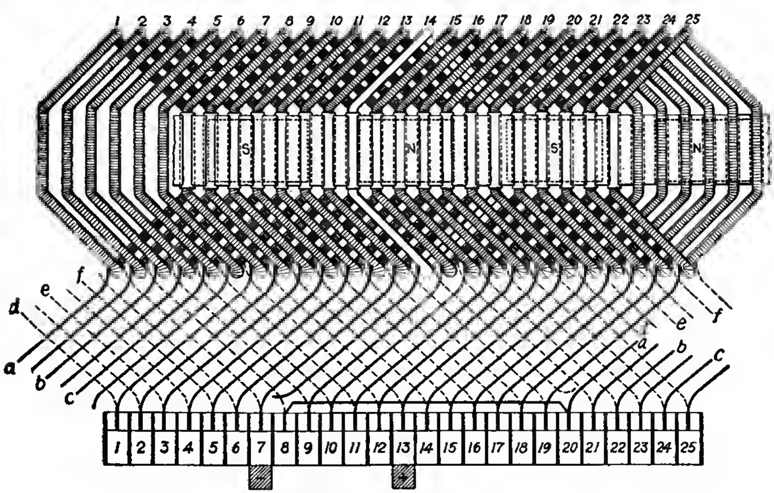


Fig. 12. Method of Cutting Out Coils in a Wave Winding

It is not an easy job to repair or cut out an open or short-circuited coil in a wave or series winding. There are several ways of cutting

out the defective coil, but the simplest and easiest way is to disconnect the leads from the defective coil and the commutator bars to which it is connected. The leads from coil *14*, which are connected to bars *8* and *20*, are removed and a jumper connected to these commutator bars. When there is a short-circuit in the coil, the rear part of the coil can be cut open like the coil in Fig. 11.

Recording Winding Data. There are certain data that should be taken from the winding and recorded before attempting to tear the winding from the armature. If the necessary data are not recorded at this time, there will be great difficulty in making the proper connections when the new coils are placed on the armature. It may also happen that the one who removed the old winding is engaged on some other work and some one else must connect the winding. It is also desirable that there be a record of the winding data kept in the repair shop, because frequently a duplicate armature may come in for repairs which has been rewound, after leaving the manufacturer's works with the incorrect size of wire or number of turns, and this error can be discovered and the correct winding applied. This will enable the motor to give more satisfactory service than before, thus pleasing the customer, who will favor that particular repair shop with more business.

It is of great help to the winder if some form is provided where he can fill in the required data taken from the old winding. A form

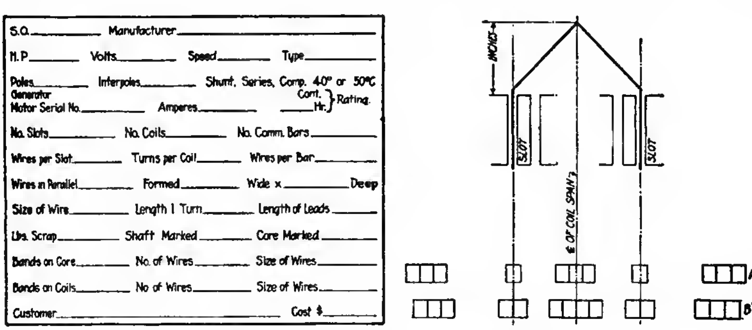


Fig. 13. Method for Recording Armature Data

similar to that used by one of the largest motor manufacturers who operate a series of service or repair stations in a number of the large cities is shown in Fig. 13. This blank form could be printed on

letter size paper, 8 x 11 inches, and then filed away with the correspondence or other papers. However, this size is not very convenient to the winder, a card about 4 inches by 6 inches or 5 inches by 7 inches being much easier to handle. When the 4 x 6 card is used, the data can be recorded on the face of the card and the diagram of connections of the coil placed on the reverse side. With the 5 x 7 card, the data and diagram can be recorded on the face side of the card. The cards can be filed away under the name of the different manufacturers, and in a short time a complete record of the windings of the different standard makes of the machines can be obtained. When the same armature comes into the shop for rewinding the second time, it is not necessary to spend the time in recording the data and a helper can be put to work removing the winding. Another very important thing is the fact that the winder may make a mistake and not wind the armature properly, and if no record was kept, this mistake would be repeated every time it was rewound.

There will occasionally be armatures that come in for repair where some inexperienced winder has attempted to modify the windings for some other speed or voltage from that on the nameplate and the marking has not been changed on the nameplate. When the customer desires that the motor operate at the speed or voltage shown on the nameplate, the correct winding data should be obtained from the manufacturer. When writing the manufacturer, all the data on the nameplate should be given and in addition all the data shown in Fig. 13, which was taken from the armature: This will enable them to identify the machine in case the serial number had been changed, which is sometimes done by unreliable second-hand dealers. While some manufacturers do not care to give out the data of their machines, they are nearly always willing to check the data that you obtain from the machine with their specifications and give you the correct data. They realize that, unless the correct winding is used, the machine will not perform satisfactorily, and this will reflect on their good name. When the repairing of motors is done by the company owning and operating them, the correct winding data should be secured for each and every motor in the plant and kept on file where it can be easily consulted when necessary to repair the motor. When the maintenance and inspection of the electrical equipment in a small factory is done by a motor repair or service

company, they should have the data in regard to the windings of all the motors in their customers' plant, so that they can render prompt and reliable service.

In the skeleton outline of the core and commutator bars shown in Fig. 13, it will be seen that there are two groups of commutator bars, marked A' and B'. In group A' the commutator bars are lined up so that the center line of the slot is on the center line of the bar, while in group B the center line of the slot is in line with the mica between the bars.

In Fig. 13 the data on the first four lines of the card can be obtained from the nameplate on the motor or generator as the case may be. It is also desirable to know whether the motor is designed for 40 or 50 degree Centigrade temperature rise above that of the room and also if the machine is intended for continuous service at the rating marked on nameplate or whcther for a shorter length of time. This last item will be of service in case the motor burns out again and there is a dispute with the customer, because that particular motor may have been designed for a 15-minute rating and naturally would soon burn out if operated at its full load continuously. The number of wires in one slot will be of service in checking to see that the other data is correct. This is equal to two times the number of coils per slot, times the number of turns per coil, times the number of wires in parallel. The number of wires per bar is the number of conductors connected to the commutator bars, and is twice the number of wires in parallel. The length of one turn and the length of the leads is of service to the winding department, in that it would be possible to start at once to wind the loops should the machine come into the shop for rewinding a second time.

The method of filling in the diagram on the reverse side of the card is shown in Figs. 14 and 15. In filling out this diagram the following should be kept in mind, and the armature and diagram should be marked accordingly.

Mark the tooth on each side of the slot that contains the bottom side of the coil with X.

Mark the tooth on each side of the slot that contains the top side of the coil with XX.

Mark the end of eaeh commutator bar with one dent from a center punch that has a lead from the top or bottom side of the coil under consideration connected to it.

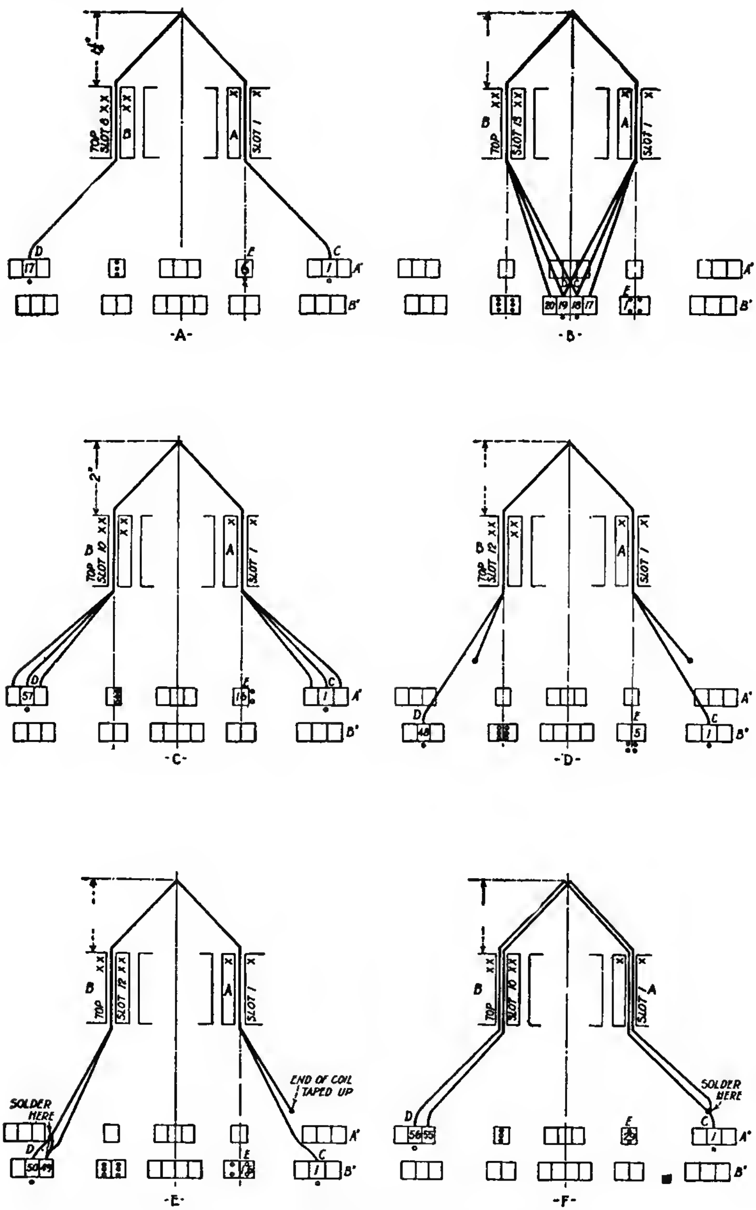


Fig. 14. Method of Connecting Coils When Brushes Are Under the Poles

Mark with two punch marks the bar that is on a center line with the side of the coil marked with one *X*. When the center line is on the mica between bars, mark each bar on both sides of the mica with two punch marks.

Mark with three punch marks the bar that is on the center line of the slot containing the top side of the coil and marked *XX*. When the center line of the slot falls on the mica between bars, mark the bar on both sides of the mica with three punch marks. When the armature has a dead coil, always use this slot for taking data and recording the information on the diagram.

When the commutator is to be removed for repairs do not punch mark the bars.

The diagram on the card, in addition to showing the same marking as the armature, should have recorded the slot numbers for the

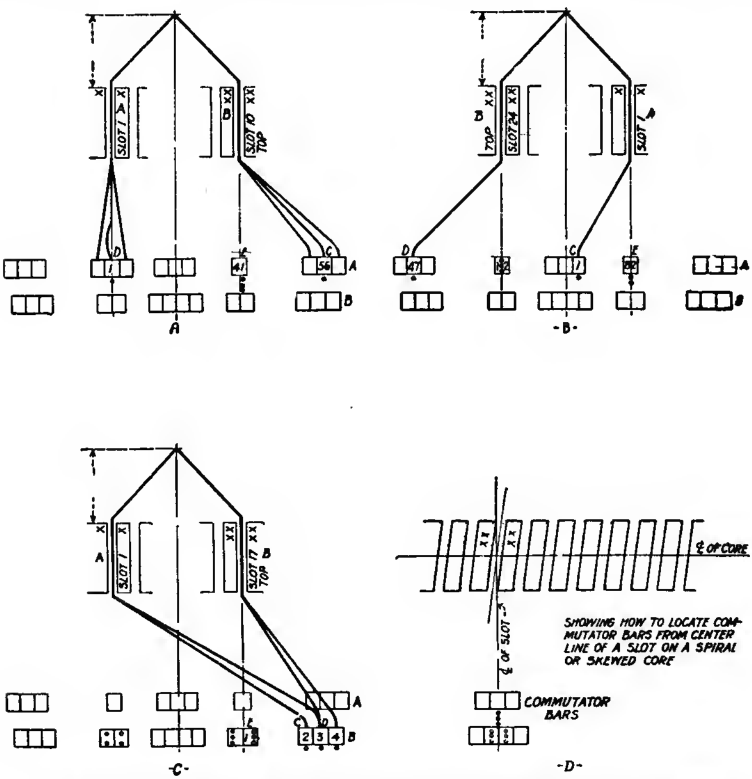


Fig. 15. Method of Connecting Coils When Brushes Are Not Under the Poles

bottom and top sides of the coil, the number of the commutator bar to which the leads are connected, and the number of the commutator bar opposite the center line of the slot in which the bottom coil is located. The slot containing the bottom side of the coil is usually

marked number *1*, and the commutator bar connected to this coil should also be marked *1*. The distance that the winding extends on the back side away from the core should be recorded so that when rewinding the back side of the coils will not be allowed to exceed this limit. If this is not watched, the back side or end of the coils may strike on the frame of the machine when it is running and wreck the armature windings.

In Fig. 14 the method of marking the diagram for a Westinghouse Type SA armature having 31 slots and 31 commutator bars is shown at *A*. It will be noted that the top side of the coil is in slot *8*, which is marked XX, and the top lead of the coil is connected to commutator bar *17*. It will be seen that the center line of the bottom slot is on the center line of the commutator bar number *6*, which is marked with two punch marks. The letters *A*, *B*, *C*, *D*, and *E* are used when it is desired to tabulate the data from a number of windings into tables where it can be easily consulted. The letters *A* and *C* always represent slot and commutator bar *1*, which is always the slot containing the bottom side of the coil and the bottom lead.

In this winding the commutator pitch is what is known as a long pitch, that is, the pitch is 16 bars. If the pitch had been 15 bars, or 1-16, it would have been known as a short pitch. Here is a case where if the winder had only marked the commutator bars and had not marked the slots in which the coil was located or the commutator bar opposite the bottom slot, it would have been very easy to insert the coils in the slots diametrically opposite and then connect the leads to the marked bars. The coil pitch would then be 1-16, and the motor would run in the reverse direction; or in case of a generator, its polarity would be reversed. If the machine had interpoles or commutating poles, it would be necessary to reverse them and connect them to the brush holder that is of opposite polarity. This condition can only happen on a four-pole machine, but this condition should be watched because the majority of motors are four-pole machines.

In Fig. 14 the connections *B* are given for a Westinghouse 50E frame, 220-volt crane or railway motor, which was used quite extensively in mine work. This is a lap winding with 52 slots and 156 coils and commutator bars. The commutator is located on the

shaft so that the center of the mica is on the center line of the slots. The commutator pitch is 18-19, or what is more often called or known as a 1-2 connection. In this winding the leads are connected to bars opposite the center line of the two sides of the coil, although they may be shifted either to the right or left, and it will be necessary to locate them with reference to bar *E*.

In Fig. 14 *C* is similar to *A* except there are three coils per slot instead of one coil per slot. This data is taken from a Westinghouse type R-7 motor which has 37 slots and 111 commutator bars. It will be seen that the center line of the slots falls on the center of the bar as in *A*, Fig. 14, which has one coil per slot and would be the same when there are five or seven coils per slot. When there are two, four, or six coils per slot, the center line of the slot would be in line with the mica between bars as in *D*, Fig. 14. There are 47 slots and 93 bars on this armature and one of the coils has the ends of the leads cut off and taped up and is referred to as the dead coil. When an armature contains a dead coil or special connections, that coil should be chosen for the diagram.

It may happen that the commutator contains an even number of bars and it is desired to use a wave winding, especially if the winding is being changed from a lap winding. The method of making the connections is shown in *E* and *F*, Fig. 14. In *E* one end of the coil is dead ended and the other side is connected to the commutator bar. A jumper is connected from this lead to the adjacent top lead and the connection is soldered. In *F* the top part of the idle coil is connected to the commutator bar while the bottom lead is connected to the same commutator bar as the other coil. In this case bar *55* has only one lead attached to it, which is a top lead.

In *A*, *B*, *C*, *D*, *E*, *F*, Fig. 14, the commutator throw is equal on each side of the center line of the coil in the slots and the brushes that bear on the commutator bars will be opposite the center line of the pole pieces. It is sometimes desirable for mechanical reasons to locate the brushes at some other location than opposite the center line of the pole pieces. Such is the case in the General Electric 51A motor, which has the coils connected as shown in *A*, Fig. 15. This armature has 37 slots and 111 commutator bars. The bottom lead is connected out straight from the slot to the commutator bar, while the top lead has all the throw. Right-hand coils are used on

this armature instead of left-hand coils as in the preceding diagrams. An armature coil is called a right-hand coil when the side of the coil that is placed in the top half of a slot is to the right of the side that goes in the bottom half of the slot. A left-hand coil would be the reverse and the top side would be to the left of the bottom side.

The bottom lead of the winding may be brought out near the center of the coil as in *B*, Fig. 15, which is the winding of a General Electric type 1000 armature which has 93 slots and the same number of commutator bars. When the length of the leads to the commutator bars from the top and bottom sides of the coils are not the same, care should be taken to give on the data sheet the correct length for the top leads and for the bottom leads. This information will enable those making the coils to provide leads of the correct length, which are usually about two inches longer than the exact length which is recorded on the card. This extra length will allow the winder to grip the wires with a pair of pliers and insert them in the slot in the riser, while if a longer length was used, more time would be required to remove the insulation and the wasted copper wire would be greater. Reducing the extra length of the leads below two inches will make it harder for the winder to insert the leads in the slot, and this extra cost will be several times the saving in copper wire.

The method of filling in the diagram for a lap-wound armature, having 32 slots and 64 segments with the connections shifted so that the brushes are located midway between the pole pieces, is shown in *C*, Fig. 15. The coil is right handed with a span of slots 1 to 17.

When the slots of the core are spiraled or skewed, as shown in *D*, Fig. 15, it is more difficult to determine which bar is opposite the slot in the core. In this illustration it will be seen that the center line from the slot is extended from the middle point of the core and not from the commutator end of the slot, as is sometimes done and which will cause trouble. A combination steel square, steel scale, or a piece of straight key stock will be of assistance in locating the commutator bar opposite the center of the slot. The scale or straight edge should be held or clamped to the core so that the amount of the tooth visible at one end of the core is equal to that under the scale

or straight edge at the other end of the core. In *D*, Fig. 15, the edge of the scale would be in line with the edge of one tooth on the back side of the core and the front edge of the tooth on the other side of the slot.

Removing Old Coils. When removing the old coils from an armature that is to be rewound, one of the coils should be removed very carefully so that it can be used as a sample by those that are winding and forming the new coils for that armature. In securing this coil the wedges should be driven out of the slots and the top half of the coil cut at both ends and that portion in the slots pried or pulled out of the slot. This process should be repeated for one or two more slots than the coil span, so that the special coil can be removed for measurements. The leads should be unsoldered from the commutator bar on this particular coil before it is removed from the slots. After removing the desired coil for measurement, the remaining coils are cut flush with the commutator side of the core and then pried or pulled out of the slot. The leads to the commutator are cut off at the edge of the coil and unsoldered from the commutator by heating the riser with a blow torch or better still with a heavy soldering iron. Care should be taken to remove all the solder when the leads are removed so that there will be room to insert the wires of the new winding. A broken hack saw blade that has its edges ground square and sharp is useful in scraping the soft molten solder from the slot in the riser. When using a blow torch to heat the commutator risers, do not allow the inner blue cone part of the flame to come in contact with the copper, or the copper will be oxidized and become very brittle, which will give trouble when the new winding is connected. Before removing the wedges from the slots they should first be loosened by hammering down on a narrow steel bar that is held on them near the teeth. They are then driven out by holding a hack saw blade on the wedge and hammering the end of the saw blade so that the teeth will be driven into and grip the wedge as it is driven out.

When the armature windings are made of copper bars or ribbon. it is sometimes desirable to use the same copper in the new winding. In removing such windings the leads to the commutator should first be unsoldered, all the slot wedges removed and then each coil should be pried out of the slot, using care not to bend the coil any more than

is necessary. The old insulation must be removed from the coils completely before they can be insulated. If high pressure steam is available, the coils can be placed in a sheet metal oven or container and live steam turned on from twelve to twenty-four hours, which will cook the insulation and then it can be peeled off very easily. The insulation is sometimes burned off the wire or copper, but this is not good practice because there is a tendency to overheat the copper and thus destroy its usefulness.

On railway and mine haulage motors a number of the large manufacturers can furnish a complete set of armature coils and all the insulation required to rewind the motor is cut exact size. These materials are of the same quality as those used in the original winding. When it is possible to secure the coils and insulations in this manner it should be done, as it is more economical and they will give better service than those not adapted for this special work. Where there are a number of these motors of the same make and size in service, a spare set of the coils and insulations should be carried in stock.

Winding and Forming New Coils. The majority of motors and generators of medium size are wound with a formed coil, and it is desirable to rewind the armature with the same kind of a coil. When the shop is equipped with a loop winder and coil spreading machine, such as shown in the section on "Winding Armatures," the new coils can be easily constructed. Without this equipment it is necessary to wind the loop and spread it to the desired shape by hand.

A simple device that can be easily constructed by any repair shop is shown in Fig. 16. This frame is constructed of one inch by three-eighths inch steel or iron bars and can be attached to the slow speed shaft of a small back gear motor that has a large speed reduction.

The material required for this frame consists of 9 feet of $\frac{3}{8}$ inch strap steel or iron, four $\frac{3}{8}$ inch carriage bolts $1\frac{1}{4}$ inches long, nine $\frac{3}{8}$ inch bolts or cap screws that have at least $2\frac{1}{2}$ inches without threads, one foot of round steel 2 inches in diameter which can be cut into disks half an inch in thickness, eighteen set screws $\frac{1}{4}$ inch in diameter and $\frac{3}{8}$ inch long, twenty-two $\frac{3}{8}$ inch hexagon nuts, and fifteen $\frac{3}{8}$ inch iron washers. The 2 inch disks are drilled off center with a $\frac{3}{8}$ inch drill, and a hole is drilled and tapped at right angles for a $\frac{1}{4}$ inch set screw. In the small detail sketch the assembly of the

disks and nuts on the bolt which fits in the slots is shown. The right-hand hexagon nut is turned on the bolt as far as possible and the threads at the back side of this nut should be flattened slightly with a blunt chisel in order to prevent them loosening up. The face of the bolts that bears on the sides of the slot should be nicked with a sharp cold chisel the same as the side of the slot, in order to prevent them from sliding out of position. The head of the bolt is cut off so that the outer disk can be slipped off easily when removing the coil that has been wound in the slot between the disks. These bolts make good guide pins that can be easily adjusted in the slots for any length of coil desired, while the adjustment for the desired coil span or pitch is obtained by adjusting the upper and lower bars

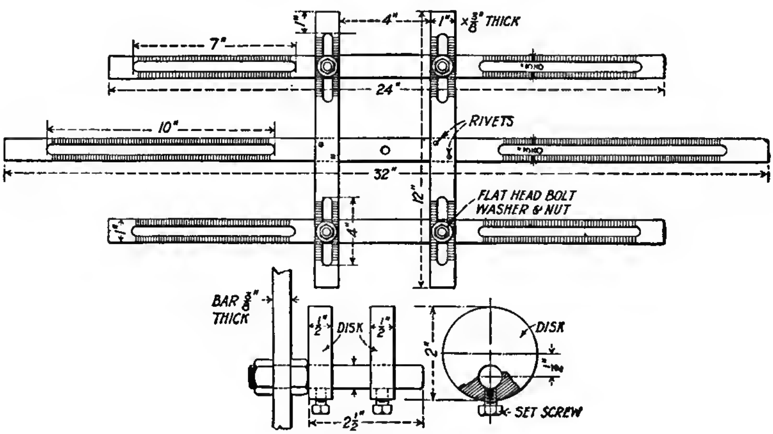


Fig. 16. Coil Former or Winder

in the slots. This form is very useful for winding concentric and threaded in type of coils used in partially closed slots of induction motors.

The methods of forming, dipping, and baking the coils and winding the armature is about the same as described in the section on "Winding Direct-Current Armatures." The connection of the armature coils to the commutator bars is easily made from the data and diagrams shown in Figs. 13 to 15 and the markings on the core and commutator bars. After being connected, tested, soldered, banded, and dipped, the armature is ready to be placed in the machine and given a running test.

REPAIRING COMMUTATOR

Commutator Troubles. The commutator of a direct-current generator or motor usually gives more trouble and needs more attention than any other part of the machine. The introduction and extensive use of undercut mica commutators has reduced and prevented a large amount of the troubles previously experienced on motors and generators. The use of commutating poles and compensating windings have also been of assistance in reducing commutator troubles, in that the heating due to sparking between the brushes and commutator has been nearly eliminated. The mica used in some of the old machines was very hard and frequently there would be a metallic streak in the center of the mica that would not be discovered until the machine had been in service for some time, making it necessary to use a very abrasive brush in order to wear it down. It was necessary to use oil or some other lubricant in order to prevent the brush from cutting or wearing down the copper bars rapidly. Frequently an excessive amount of oil would be used on the commutator and it would soak down in the mica and become carbonized, thus forming a conducting path between the two bars. When carbon is heated, its resistance decreases instead of increasing, as is the case with most metals, thus allowing more current to flow and become still hotter until it would be red hot. This action, if allowed to continue for some time, would cause the edges of the bar at these points to be melted and form a small hole or cavity which would become filled with carbon and copper dust, a still better conductor. This condition will soon become similar to a short circuit of the coil connected to those bars and cause these coils to burn out.

If the above condition is taken care of in time, the carbonized spot can be scraped and the cavity filled up with a good commutator compound or cement. The commutator cement can be purchased from a reliable electrical supply house or it can be made from the following materials: One part powdered mica, two parts plaster-of-paris, and enough of shellac to make a thick paste. This compound dries very rapidly and has about the same degree of hardness as the mica between the bars, and will wear down at about the same rate. When the mica becomes burned deep down in the

commutator, it then becomes necessary to take the commutator apart and replace it with a new mica segment. The method of holding or clamping the commutator bars and mica segments in a commutator is explained in the section on "Armature Construction."

Dismantling Commutator. When taking a commutator apart, the bolts, cap screws, or nuts must be removed so that the front steel clamping ring and mica V ring can be taken off. The clamping ring should be marked before being removed in order that it can be replaced in the same position. If this ring cannot be loosened by tapping with a hammer, the commutator will have to be heated to an even temperature all around with a blow torch as the mica V ring was stuck on with shellac. This will soften the shellac and cause the bars to expand enough to enable the front end rings to be removed. The commutator bars can be pried apart and the defective mica segments removed from between them. A very thin hack saw blade or piece of steel will be of assistance in removing the mica, although it may be necessary to unsolder the commutator bar and scrape the mica off especially if shellac was used when the commutator was assembled. In cutting mica segments it will be much easier and better if the sheet mica is pasted to the bar with shellac, as there will not then be any tendency for the bar to slide out of position. The bar and mica can then be replaced as a unit in the commutator and there will not be any tendency for the mica to slide out of its proper place. It is not advisable to shellac both sides of the mica because this may prevent the commutator bars from coming into proper position when the commutator sleeve is tightened.

Tightening Commutator. When the complete commutator has been removed from the shaft and reinsulated, the clamping bolts or nuts should be set up as tight as possible, the ends of the commutator bars at the V rings should be shellacked and the complete commutator placed in an oven and baked. The commutator should be cooled quickly with a blast of air and the nuts tightened as fast as the copper contracts. When the commutator has not been removed from the shaft or the bars have not been unsoldered, the commutator can be heated with a blow torch or better still with an electric heater. A very good electric heater can be constructed by wrapping a sheet of $\frac{1}{32}$ or $\frac{1}{16}$ inch asbestos paper around the commutator and winding about 30 feet of No. 18 Nichrome wire on top of the paper and then

another layer of asbestos paper on top of the Nichrome wire. The Nichrome wire should be spaced uniformly apart on the commutator and connected to a 110-volt lighting circuit. When only 220 volts are available, the length of the wire should be doubled, or else a variable resistance placed in series with this wire. Care must be taken to see that all crevices between the bars and mica end rings are filled with shellac so that carbon dust cannot work down under the ends of the bars and cause trouble.

Repairing Mica V Rings. It frequently happens that oil will work up to the edge of the mica V ring from the shaft of the motor and cause the insulation to carbonize due to carbon dust collecting at this point. This will produce a short or ground between the commutator bars and the frame. This defect will not usually be

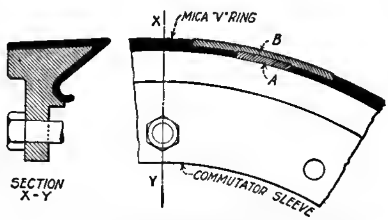


Fig. 17. Method of Repairing Mica V Ring

noticed until some disturbance, such as a short circuit on the feeders or distribution system or in case of a motor the application of a heavy load very suddenly, causes a flash over or arc between the commutator bars and the commutator sleeve. The flash over or arc will carbonize or burn out the mica, making it necessary to patch or replace the V ring. When the defect is confined to one spot the mica ring can be repaired by removing the commutator sleeve and cutting out the defective spot as shown at *A* in Fig. 17. The mica on all sides of this spot should be cut down to about half thickness as shown at *B*. Pieces of mica *A* and *B* should be cut to fit snugly in the mica V ring and should be secured in place with shellac. This manner of breaking the joints prevents the current from leaking through at the edge of the patch.

A different grade of mica is used for the V rings than what is used for commutator segments. The mica used between segments is composed of flakes of mica cemented together with a cement that is

not affected by heat, while shellac is used as a binder on the mica plate from which the V rings are made. When the mica is heated, the shellac softens and allows the small particles of mica flakes to slide past one another so it can be molded to any desired shape.

Undercutting Mica. The use of undercut mica commutators is becoming greater each year and many commutators that originally had flush mica are being undercut so that a soft graphite brush can be used which will furnish the required lubrication automatically. When a motor or generator is being overhauled or repaired, it is advisable to undercut the mica and change the brushes to the proper grade for this class of work. This will eliminate all trouble due to high mica and will reduce the wear on the commutator and thus increase the life of the machine several years.

There are a number of hand machines available that can be purchased which are very desirable where a large amount of this kind of work is done. In the small shop the mica is usually undercut by hand using a file or scraper made for this work. If the commutator

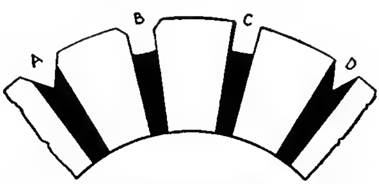


Fig. 18. Proper and Improper Methods of Undercutting Mica

has been placed in a lathe and a fine cut taken from its surface in order to true it up, a sharp pointed tool can be placed in the tool post and forced by hand back and forth along the mica several times thus scraping the mica to the desired depth. An old hack saw ground to the proper shape makes a very good tool for this kind of work, as well as being useful for cutting or removing any mica left when undercutting machines are used. Several layers of tape can be wrapped around one end of the hack saw blade to form a handle. A piece of flat steel can be held against the risers and its side used as a guide for the first few strokes of the saw blade until a guide or groove is formed which will prevent cutting the copper bars. The mica should be cut to a depth about equal to the width, which is from $\frac{1}{32}$ to $\frac{1}{16}$ of an inch, and the edges of the commutator bars should

be beveled as shown at *A* and *B* in Fig. 18. The type of slot shown at *A* should be used when the machines are located in a very dusty place or operated at a slow speed in order that there will not be any chance for dirt to collect in the grooves. The square type of slot shown at *B* is used on railway and high speed motors where centrifugal force will keep the slot clean. Two examples of improper cutting of mica is shown in Fig. 18 at *C* and *D*. At *D* the mica has not been cut below the surface of the commutator and the brushes are not hard enough to wear it down. At *C* the mica has not been removed from the left-hand side of the slot and the cutter has dug in and cut part of the bar on the right-hand side, while at *D* the slot has not been cut deep enough. The slot at *D* should be extended deeper and cut the copper as at *A*. When the mica has been cut or removed with a machine, the commutator should be gone over with a fine file and the burrs and edges of the commutator bars rounded and the mica removed from places where it was overlooked or missed.

When the commutator of a motor with flush mica is turned or a cut taken from its surface in a lathe and the mica is undercut, it is necessary to change the grade of brush used on that machine. The brush used with a flush mica commutator contains harder and sharper carbon in order to cut the mica and thus wear it down evenly with the copper bars. With undercut mica a very soft carbon or graphite brush is used, which does not cut the commutator but tends to polish it and give the dark chocolate color so much desired by those operating and maintaining direct-current machinery.

WINDING ALTERNATING-CURRENT MOTORS AND GENERATORS

Introduction. The construction of an alternating-current motor or generator is quite different from that of one used on direct current. This difference in construction has been described in the sections on Types of Generators and Motors.

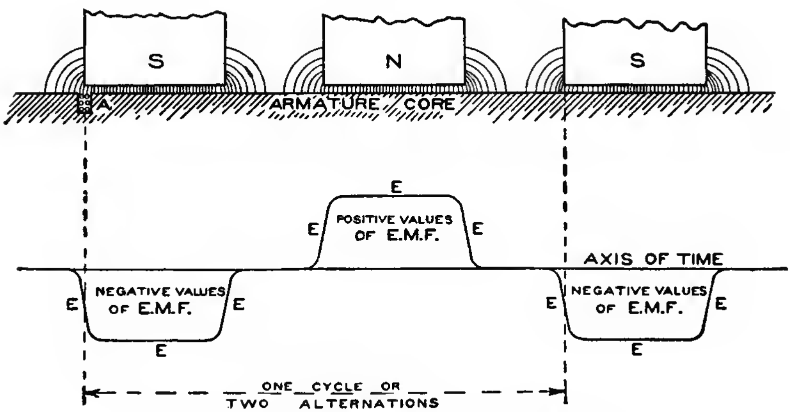


Fig. 1. Development of magnetic fields and E. M. F. curve.

The difference is necessary because alternating current does not flow all the time in the same direction like direct current, but flows first in one direction and then in the reverse direction. With direct current the voltage is at a fairly constant value. With alternating current the voltage increases from zero to a maximum negative value, then decreases to zero and rises to a maximum positive value, and then falls to zero, as shown in Fig. 1. In this figure the armature core is assumed to be moving to the right under the pole pieces marked *S* and *N*, which are stationary. The armature conductors are shown in slot *A*. For simplicity, only one slot is shown in the armature core and one set of armature conductors. When the armature conductors *A* move under the south pole, a negative electromotive force or voltage is generated; and as soon as the conductors pass from under the right-hand edge of this pole, the voltage

decreases to zero and remains so until the armature conductors begin to move under the north pole. The voltage wave then increases in positive value to maximum and decreases toward zero as the armature conductors move beyond the right-hand edge of the north pole. The passing of the armature conductors under a south and a north pole produces one cycle of electromotive force or voltage. Thus it is necessary for the armature conductors to move under 2 poles (one pair of poles) in order to produce one cycle.

In commercial work the frequency is expressed in the number of cycles per second, which is usually either 25 or 60 cycles. Thus on a generator producing 25 cycles it is necessary that the armature

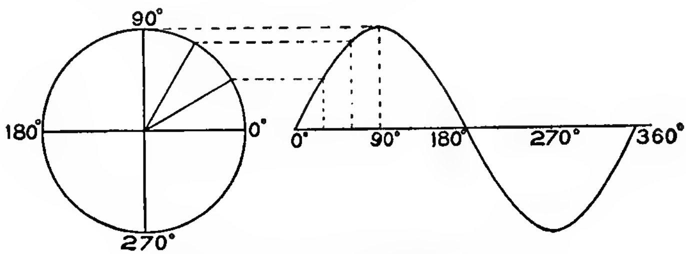


Fig. 2. Method of plotting sine E. M. F. curve.

conductors pass under twenty-five pairs of poles in each second. In commercial generators there is more than one armature coil per slot and several coils are connected in series which, instead of producing a voltage that is represented by a flat-top wave as shown in Fig. 1, produces one that is more of a sine curve, Fig. 2. The method used in plotting or drawing a sine curve is also shown in Fig. 2.

The voltage curve representations shown in Figs. 1 and 2 are produced by a single-phase generator. In a two-phase generator there are two separate windings each of which produces a voltage curve similar to Fig. 2. These voltage curves or waves are 90 electrical degrees apart, as shown in Fig. 3. In the left-hand side of Fig. 3 the voltage wave A is at its maximum positive value and the voltage wave B is at zero. When B reaches a maximum positive value, A is at zero; and when A reaches a maximum negative value, which is 180 electrical degrees from the beginning, B is at zero. Thus wave B is always 90 electrical degrees behind wave A. The

voltage waves must pass through 360 electrical degrees before the cycle is repeated. In a generator or motor the 360 electrical degrees

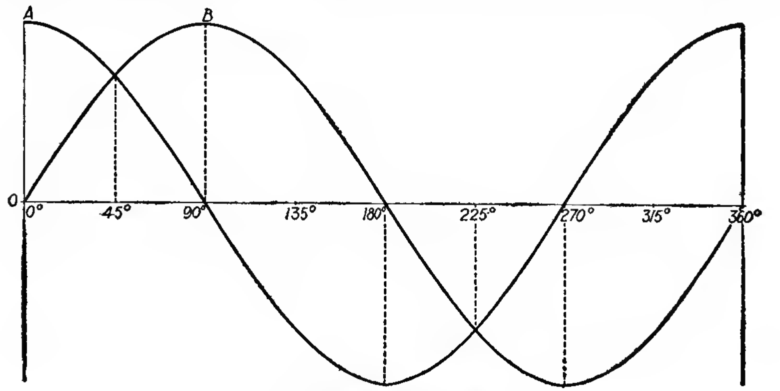


Fig. 3. Two-phase sine voltage curve.

would be the distance from the center of one pole to the center of the next pole that has the same polarity. On a 2-pole machine 360 elec-

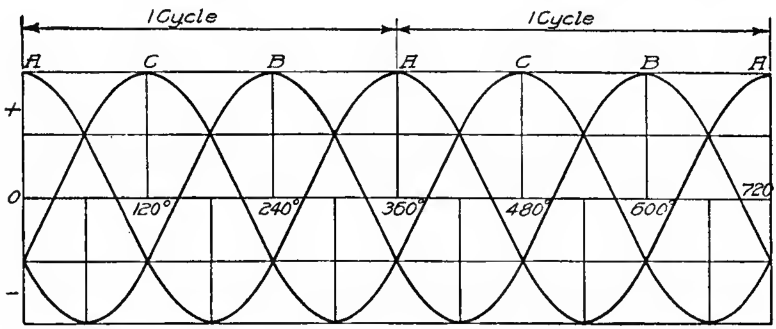


Fig. 4. Three-phase sine voltage curve.

trical degrees is one revolution, while on a 4-pole machine it would be one-half of a revolution. The voltage wave *A*, Fig. 3, is produced by one of the phase windings of the generator and for identification is referred to as phase *1* or phase *A*, and the voltage wave *B* is produced by the other phase winding called phase *2* or phase *B*.

In a three-phase alternator the voltage waves of the different phases are 120 electrical degrees apart, as represented by the curves shown in Fig. 4. Thus the voltage of phase *A* is at a maximum positive value, while that of phases *B* and *C* is half of the maximum

negative value. It will be seen that the voltage of phase C is decreasing, while that of phase B is increasing toward a maximum negative value. After the armature coils have moved 120 electrical degrees, which is one-third of the distance between two poles of like polarity, phase C has reached a maximum positive value, while phases B and A are each half of the maximum negative value. At 180 electrical degrees, or the distance from one pole to the next pole, the voltage wave of phase A is at a maximum negative value, while phases B and C are at one-half of the maximum positive value. This is just the reverse of the condition at the start. The voltage waves of the three phases, A, C, and B, increase in progressive order, each being 120 electrical degrees behind the other one.

MAGNETIC FIELDS

Single-Phase Magnetic Field. The magnetic circuit through the frame and armature of a direct-current machine is shown in Fig. 5. The direction of flow of the current in the wires is indicated

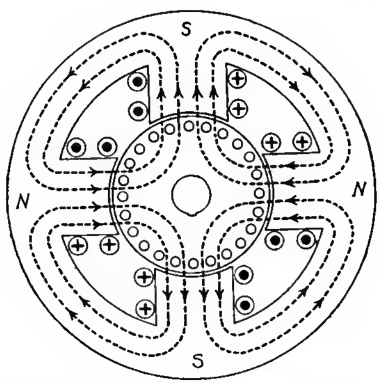


Fig. 5. Magnetic field of a direct-current machine.

by the crosses and dots in the circles. A cross indicates that the current is flowing away from the observer and a dot indicates that it is flowing toward the observer. In Fig. 5 it will be seen that the direction of the flow of current in the wires on the adjacent side of any two pole pieces is always in the same direction. The space between the pole pieces could be narrowed up to form a slot, Fig. 6. In this figure there are only two conductors in each slot and the

windings are connected in series with each other. This is a simple diagram of the windings of a single-phase motor. In Fig. 3 the voltage of phase *A* is a maximum positive value at the instant represented by zero degrees. If this phase is connected to the terminal

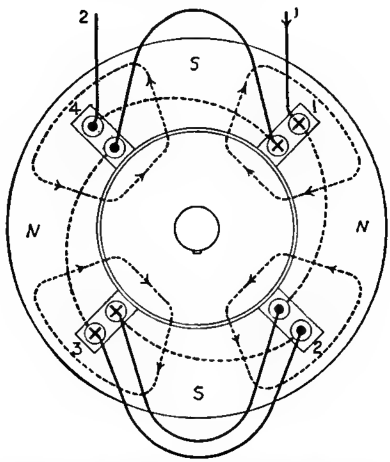


Fig. 6. Magnetic field for a single-phase motor.

wires of the motor shown in Fig. 6, the direction of the flow of current through the conductors at this particular instant will be as shown in Fig. 6. The direction of the flow of magnetic lines of force through the stator core and the rotor core is as indicated by the dotted lines with the arrowheads. The north pole is located between slots *1* and *2* and *3* and *4*. In Fig. 6 the dotted lines indicate the connection of the armature coils at the rear end of the stator core, while the full lines indicate the connections on the front side of the core. At 90 electrical degrees later in time, the voltage will have dropped to zero and there will not be any current flowing through the conductors in the slot. The magnetic poles, however, will retain their same position and polarity, because a slight amount of magnetism is retained by the iron in the core.

As the voltage wave of phase *A*, Fig. 3, advances from 90 to 180 electrical degrees, it will be of a negative value and the flow of current will be the reverse of that shown in Fig. 6. This condition is indicated in Fig. 7. It will be seen that the north pole is now between slots *2* and *3* and *4* and *1* and the poles have advanced one-

fourth of a revolution, which is half the distance spanned or covered by one pair of poles. As the voltage wave decreases from maximum negative to zero value at 270 electrical degrees, the strength of current through the windings and the magnetism produced will also decrease. As the voltage wave increases in positive value from 270 electrical degrees to 360, the magnetic poles shown in Fig. 7 will reverse and then become as shown in Fig. 6, because the voltage

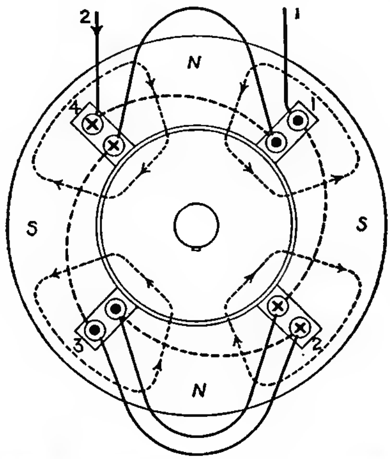


Fig. 7. Magnetic conditions one-half cycle later than Fig. 6.

wave has completed a cycle and is the same as at zero degrees. Thus it is seen that the polarity of the poles is reversed once for each cycle. This condition is repeated sixty times every second for a 60-cycle circuit. It will be seen that there is no tendency for the magnetic poles to rotate or revolve around the stator windings and cause the rotor to revolve.

Two-Phase Magnetic Field. In Fig. 8 an end view of the conductors for phases A and B of a two-phase motor are shown. For simplicity, the connection between conductors and groups of conductors are not shown. However, they are connected so that the current produced by the voltage wave of phase A flows through all the conductors marked A. Likewise the current produced by the voltage wave of phase B flows through all the conductors marked B. The A and B groups of conductors are insulated from each other and

are two separate and distinct electrical circuits. There are two leads from the phase *A* winding and two leads from the phase *B* winding of the motor which are connected to the source of supply. Referring to the two-phase voltage wave, Fig. 3, at zero degrees the voltage of phase *A* is maximum and the flow of current through the conductors in the winding is as shown in Fig. 8. The voltage wave

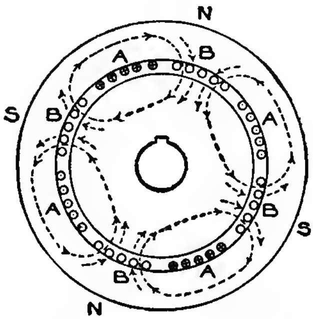


Fig. 8. Path of magnetic field of a two-phase motor.

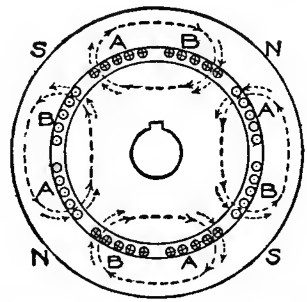


Fig. 9. Magnetic path one-eighth cycle later than Fig. 8.

for phase *B* is zero and there will not be any current flowing through this winding in the motor. Thus there will not be any magnetism produced by this phase winding.

Next consider the voltage waves 45 electrical degrees later, which is one-eighth of a cycle. The voltage waves of phases *A* and *B* are both positive and the current flowing through the windings of the motor would be the same in both phases *A* and *B*. The direction of the flow of current and the path of the magnetic lines of force and poles are shown in Fig. 9. The voltage wave of phase *A* at 90 electrical degrees, Fig. 3, has dropped to zero and that of phase *B* has increased to the maximum positive value. At this instant there will not be any current flowing through the phase *A* winding of the motor as indicated in Fig. 10. All the magnetism produced at this instant in the stator core is that from the phase *B* winding. By comparing Figs. 8 and 10 it will be seen that the north pole has moved clockwise from opposite the center of the winding of phase *B* to the center of the winding of phase *A*. The distance that the magnetic poles have moved is one-eighth of the revolution for this particular motor. As the voltage waves of the two phases move from 90 to 360 electrical degrees, the magnetic poles will continue to move in a clock-

wise direction. The distance that the magnetic poles will move in one cycle will be four times one-eighth of a revolution or one-half of a revolution. This particular motor has 4 poles and the rotor has moved past 2 poles or one pair of poles during one cycle or 360 electrical degrees.

If the action of the magnetic field for a two-phase motor be compared with that of a single-phase motor, it will be seen that the

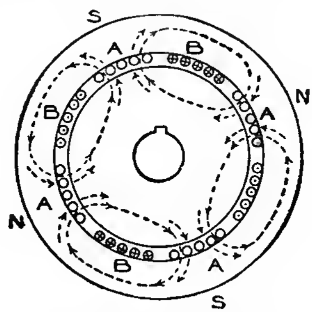


Fig. 10. Magnetic path one-fourth cycle later than Fig. 8.

magnetic field of a two-phase motor tends to revolve around the stator in a certain definite direction. In the single-phase winding, however, the magnetic poles were first in one location and then in the other, and there was no tendency for it to rotate in a given direction. If the windings of a single-phase motor, Fig. 6, were connected to a supply line, its armature or rotor would hum and would not tend to rotate. If, however, the rotor is brought up to nearly the same speed as the change in the magnetic poles due to the frequency of the supply circuit, this motor would then continue to run at the same speed as the magnetic fields change position. It is thus necessary to use some means for starting a single-phase motor. This is usually done by means of a starting winding or other devices which will produce a rotating magnetic field. The two-phase motor shown in Fig. 8 will run if one of the phases is disconnected after it has been brought up to speed. The same condition is true of three-phase motors.

Speed of Alternating-Current Motors. The speed of an alternating-current motor depends on the frequency (number of cycles per second) of the supply circuit and the number of poles formed by

the motor windings. When the voltage and current waves have passed through one cycle (two alternations), the rotor will have revolved through that portion of the revolution represented by 2 poles. If the stator is wound so as to give 4 magnetic poles, the rotor will have made $2 \div 4$ or $\frac{1}{2}$ of a revolution. Thus the speed of a motor in revolutions per minute (r.p.m.) is equal to the number of alternations per minute divided by the number of poles formed by the winding.

The frequency of an alternating-current circuit is expressed in cycles per second. In order to obtain the number of alternations per minute, it is necessary to multiply the number of cycles by the number of seconds in a minute, which are 60, and by 2. The majority of alternating-current power circuits have a frequency of either 25 or 60 cycles per second. In this case the number of alternations per minute would be $25 \times 60 \times 2$, or 3000 for 25 cycles and 7200 for 60 cycles. Thus the speed of a 4-pole, 60-cycle motor is $7200 \div 4$ or 1800 r.p.m.; a 6-pole motor is 1200, and an 8-pole motor is 900 r.p.m.

The rotor of an induction motor does not run at the synchronous speeds given above when carrying full load, but lags behind the synchronous speeds. This lag is usually referred to as the "slip" of the motor. At full load this slip is usually from 3 to 5 per cent of the synchronous speed. For this reason the speed of a commercial motor is frequently rated at its full-load speed instead of the synchronous speed. As an example, the speed of a 60-cycle, 4-pole induction motor is frequently given as 1750 r.p.m. instead of 1800.

TYPES OF COILS

Stator Coils. The types of coils used in winding alternating-current motors and generators are very similar to those used for direct-current machines. The diamond, involute, concentric, and shuttle-type coils have been described in the section on Winding Direct-Current Armatures. The diamond-type coil is used very extensively in winding the stators on induction motors. The leads of this coil are brought out near the point of the diamond so that a number of the coils lying in adjacent slots can be connected in series in order to form a phase group. When a partially closed slot is used, it is necessary to use a threaded-in type of coil, which can be wound

in the same manner as the diamond coil. The ends of the coil which will project beyond the core are insulated with cotton and linen tape, while the part of the coil that fits in the slots has only the double cotton covering on the wire to protect it. In using this type of coil it is necessary to provide sufficient insulations in the slots and between the coil sides in the same slots to take care of the electrical requirements.

Skein Coils. The skein type of coil is used very extensively on small single-phase motors. This type of coil is usually wound in the shape of a rectangle or oval, and then the sides of the conductors are inserted in the slot and looped back and forth as shown in Fig. 11.

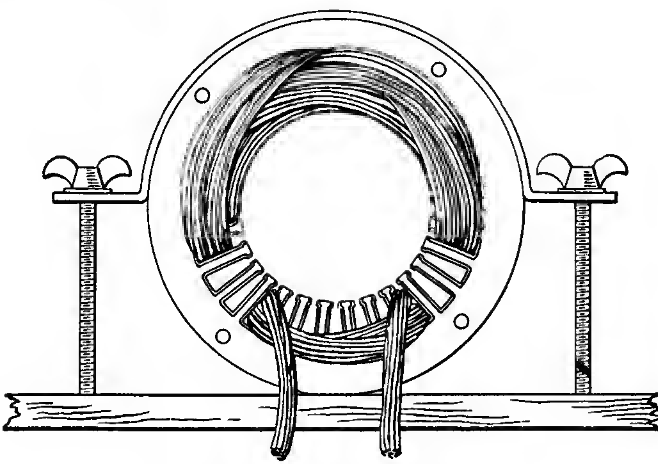


Fig. 11. Winding skein coils in slots.

After the skein is wound on the former, it is usually taped at four to six places in order to keep the wires from becoming tangled. In Fig. 12 a group of skein coils are shown lying on the workbench and also hung in the racks over the heads of the armature winders. In this type of coil the sizes of wire used are usually smaller than No. 18, in order that they may be flexible enough to be easily inserted in the slots. When it is necessary to have conductors of greater area than No. 18, two or three wires of smaller size can be used in parallel.

Rotor Coils. The rotors of an induction motor frequently have conductors wound in the slot and insulated from each other

in a manner similar to direct-current armatures. The method of connecting the coils is similar to that used in the stator winding. Frequently these rotor coils are wound out of bar or strap copper or

Fig. 12. Modern coil-winding room.
Courtesy of the Domestic Electric Company

heavy, double cotton-covered wire and formed so that all the coils for one phase group are made from one piece of copper. A view of such a coil is shown in Fig. 13. These coils usually occupy several slots. The advantage of this connection is that the only splicing or connecting of conductors necessary is that connecting different phase groups.

With the squirrel-cage type of rotor, bare copper bars are driven into the partially closed rotor slots from the end of the core. A slot insulation, usually of asbestos paper, is inserted in the slots of the large-sized rotors before the bars are driven into place. On the small sizes it is not necessary to insert insulation between the rotor bars and iron laminations of the core on account of the extreme low voltage of the current in the bars. The ends of the copper bars are lined up and soldered or riveted to a circular copper ring, or else placed in a mold and a copper ring cast in place around the bars, Fig. 14.

WINDING SINGLE-PHASE MOTORS

Split-Phase Windings. Single-phase alternating-current motors that are one-half horsepower or less in size are usually started by the split-phase method. When starting by this method there are

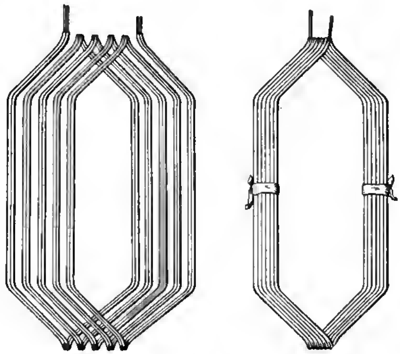


Fig. 13. One-piece pole-phase rotor coils.

two separate electrical circuits in the stator that are connected in parallel with each other, Fig. 15. These two circuits are known as the running and the starting windings. The starting coils or wind-

Fig. 14. Squirrel-cage rotor with cast-on rings.
Courtesy of Fairbanks, Morse and Company

ings are placed in slots in the stator that are midway between the slots containing the main or running coils. After the rotor has attained about two-thirds of its rated speed, the starting-winding circuit is opened by means of a centrifugal switch, and the motor then operates on the running winding as a single-phase motor. The starting and running windings do not have the same number of

turns or size of wire. Thus the reactance of one of the windings will be greater than the other one and will hold back the current flowing through that winding more than the other one. The magnetic poles produced by one winding will reach maximum value before the other and a revolving magnetic field similar to that shown in Figs. 8 to 10 for a two-phase motor is produced.

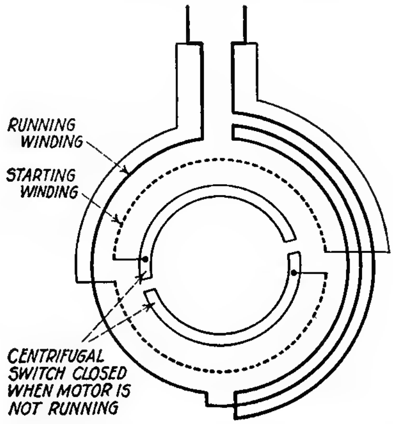


Fig. 15. Conventional wiring diagram of a single-phase motor.

Recording Data. The method of recording the winding data is shown in Fig. 16. This information is frequently recorded on printed 4- by 6-inch cards, which can be filed under customer's name or order number. The information contained on these cards is usually furnished by the Specification Department to the shops and gives them all the required data.

This same card can also be used for repair shops that make a practice of rewinding different makes of single-phase motors. The information contained on this card would then, of course, be obtained from the motor winding before it is torn down. In rewinding motors it is especially desirable to mark slot *1* so that it can be identified and the winding placed in the correct position.

In winding new motors, the starting winding should be located so that the bulk of the winding will be between the bolts or studs on the stator and will not interfere with the mechanical assembling of the machine. Referring to the data in Fig. 16, the bulk of the windings would be opposite the ends of slots *8* and *9* and these slots

should be located midway between the bolts or studs that fasten into the stator frame.

Customer A. B. Electric Co. Order No. 21644
Make Domestic Electric Co. Type IW Serial No. 26428
H.P. 1/4 Volts 110 Cycles 25 Phases 1 R.P.M. 1450
No. Poles 2 No. Slots 30 Coils are ~~Form,~~ Skein, ~~Hand~~ Wound
MAIN WINDING 15 turns No. 18ESCC wire per coil-- No. Coils
Coils Connected Series Length of turn 62 & 88 in. Lbs. Wire 1.9
STARTING WINDING 19 turns No. 23ESCC wire per coil-- No. Coils
Coils Connected Series Length of 1 turn 77½ in. Lbs. Wire 0.4

Slot No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Main Winding	15 15	30	30	30	30	15					15	30	30	30	30	15 15	30	30	30
Starting Winding						19	38	38	38	38	19								
Comp. Winding																			

Fig. 16. Single-phase motor data card.

Forming Coil. It will be seen by referring to the winding data given in Fig. 16 that for this particular motor a skein winding is used composed of fifteen turns of No. 18 single cotton enamel covered wire for the main or running winding. The lengths of one turn of the skeins are 62 and 88 inches, respectively. The starting winding is composed of nineteen turns of No. 23 wire and each skein is 77½ inches long. This particular motor is used on a 25-cycle circuit and has 2 poles. Due to the winding being bulky it is much easier and more desirable to use two skeins in winding each pole instead of using one skein, which would be very unwieldy to handle. In winding split-phase induction motors on the small sizes it is universal practice to use single cotton enamel covered wire.

Insulating the Core. The majority of single-phase motors are used on either 110 or 220 volts and one thickness of 0.007-inch fish paper is used for insulating the slots. The insulation in the slots should extend from ¼ to ½ inch beyond the end of the slots so that they will protect the windings from coming in contact with the sharp corners of the slot. A layer of 0.007 empire or treated cloth is

used between the coils and the fish paper in order to provide additional electric insulation. When the sides of a coil of a different phase group or pole are placed in the same slot they should be separated from each other by the use of 0.007-inch empire paper or treated cloth. The same kind of insulation should be used between the running and the starting windings when they are placed in the same slots. Asbestos paper 0.010 inch in thickness is often used between the running and starting coils instead of the treated cloth. The reason for using asbestos paper is because it is not as good a heat conductor as the treated cloth; and in case the starting winding becomes overheated due to failure of the centrifugal device to open the circuit after the motor has attained speed, the running windings will be protected from injury. In case a motor should stall, the starting winding is almost invariably the one that burns out. The use of asbestos paper will confine the burning out of the starting winding to itself and will prevent the insulation from becoming charred on the running winding. The starting winding is the last one to be placed on the core and can bc replaced much easier and cheaper than winding the whole machine.

Skein Coil Winding. By referring to the data contained in Fig. 16 it will be seen that there are fifteen turns of the main winding in slots *6* and *11* and the skein is pulled through these slots as shown in *A*, Fig. 17. In this figure half of the skein is shown solid, while the other half is indicated by two light lines. It is drawn in this manner to show clearly the path each side of the skein takes in being wound in place. After the skein has been placed in slots *6* and *11*, it should be pressed and hammered tightly against the core. The wires should be arranged so that they tend to lie flat against the core and should not be twisted like a rope. It is best to use a wooden or rawhide mallet when pushing or hammering the wires down in place. When such a mallet is not available, they can be hammered in place by holding a piece of heavy fiber on top of them and hammering the fiber. This will prevent injuring the insulation while they are being pushed to position. After the skein is pulled through slots *6* and *11* as shown in *A*, Fig. 17, it is then given a half twist from right to left as shown in *B*, Fig. 17. The skein is then doubled back and passed through slots *5* and *12* as shown in *C*, Fig. 17. It is then given another half turn,

this time from left to right as shown in *D*, Fig. 17. The reason for making the half turn from left to right instead of like the turns in *B*, Fig. 17, is because it does not twist the wires in the skein as

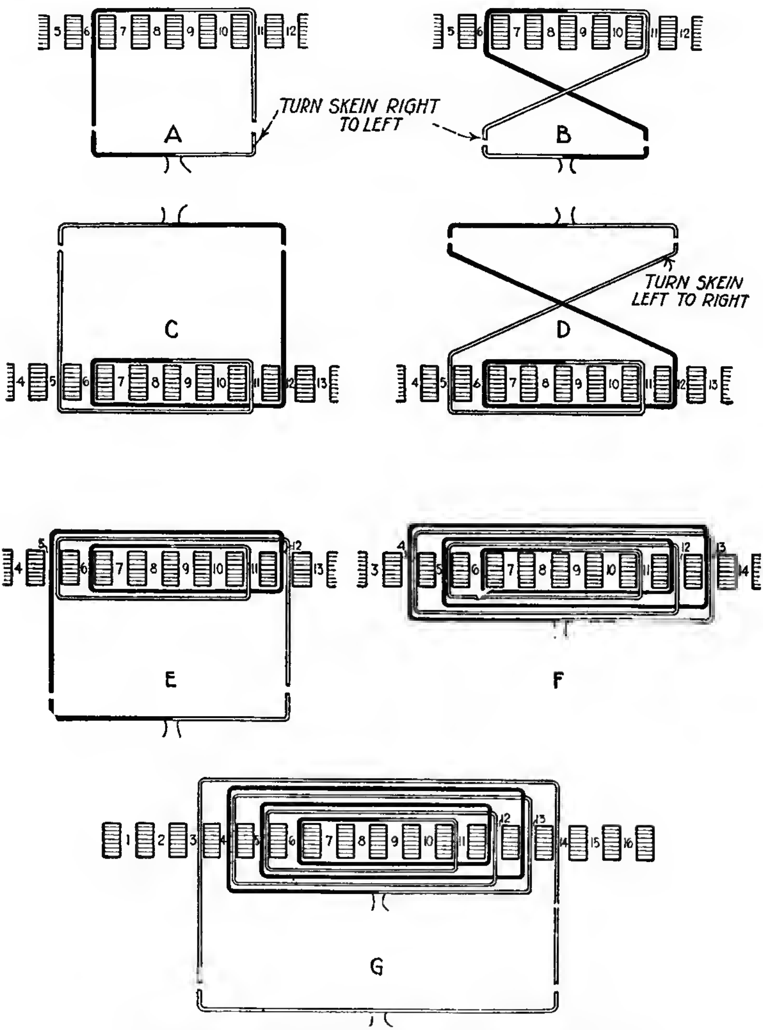


Fig. 17. Method of inserting skein-type coils in stator slots.

much as when the same turn is made on both the front and back ends of the core. With some windings it is immaterial whether the half turn is made the same on both ends or not, because there

is sufficient space for the winding on the core. The skein is then inserted back through slots *5* and *12* as shown in *E*, Fig. 17, and again twisted and passed through the next slot—an operation which is repeated until the slots are filled as shown in *F*, Fig. 17. This completes the winding of the first skein in the slots.

The second skein, which in this particular motor is 88 inches in length, is then passed through slots *3* and *14* as in *G*, Fig. 17. Its end is then given a half turn and passed back through the same slots and the operation repeated until the slots are filled according to the winding data given in Fig. 16. It will be noted from the data that there are two coils of fifteen turns each in slots *1* and *16*.

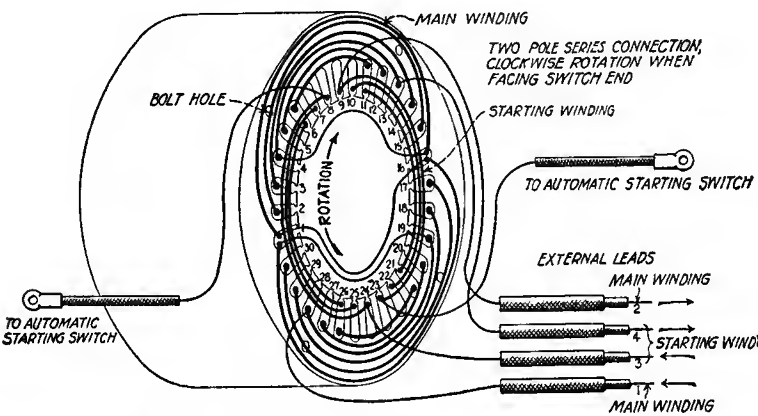


Fig. 18. Wiring diagram for the stator of a single-phase motor.

When completing the main winding of the first pole, the skein is placed in slots *1* and *16* only once, the same as shown in *A*, Fig. 17, for slots *6* and *11*. When the main winding is placed on the other pole, which is diametrically opposite it in the stator core, the end of the second skein will lie in the top half of slots *1* and *16*. The main winding for all poles is first placed in position and the starting winding is afterwards inserted in place.

The starting winding is inserted in place in a manner similar to the main winding. The first side of the starting winding is passed through slots *6* and *26* and then doubled twice through slots *7* and *25* and *8* and *24*. On this winding, which does not contain nearly as much wire as the main winding, it is only neces-

sary to use one skein; the other half of the starting winding, which is diametrically opposite, is passed through slots *11* and *21* once and then doubled back twice through slots *10* and *22* and *9* and *23*. A type of winding diagram used by several manufacturers for this particular connection is shown in Fig. 18.

In this diagram the winding is definitely located on the core by means of bolt holes in the stator core. One of the bolt holes is opposite the bottom of slot *5*, and the other one is opposite the

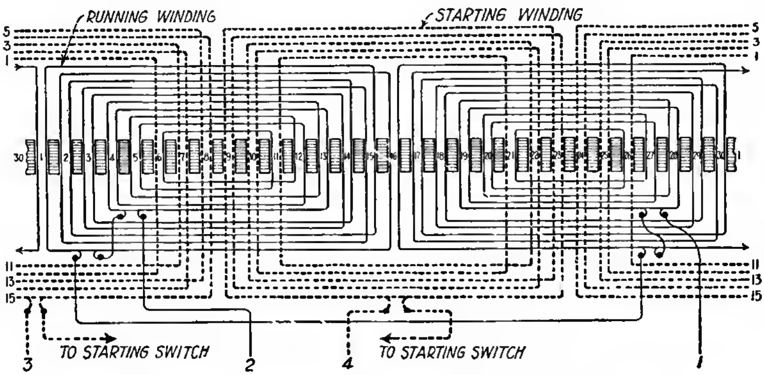


Fig. 19. Complete winding diagram showing method of connecting skein coils.

tooth between slots *12* and *13*. The bulk or mass of end connections of the main winding is located midway between these two bolt holes. These holes are used in clamping the bearing brackets to the stator core and frame.

A complete wiring diagram of the same motor is shown in Fig. 19. In this figure the dotted lines indicate the starting winding, and the full lines the main or running winding. The external leads marked *1* and *3* are connected to one of the line leads, and leads marked *2* and *4* to the other line lead. When the motor is standing still, the circuit through the starting winding is completed by the starting or centrifugal switch. Closing the line switch will allow current to pass through the two parallel windings and thus produce a rotating magnetic field similar to that obtained in a two-phase motor. As soon as the rotor attains about one-half to two-thirds of its normal speed, the centrifugal switch opens the circuit through the starting winding and the motor operates as a single-phase motor.

Hand Winding. The insulated wire is wound directly from the spool into the slots by hand and the stator core is insulated in the same manner as when the skein winding is used. The slot insulation should extend at least $\frac{1}{4}$ to $\frac{3}{8}$ of an inch beyond the edge of the core. The slot numbers into which the first coil is wound are obtained from the specifications or data sheet. Assuming that the data contained in Fig. 16 is used, the first coil to be wound is the one in the center of the main winding, which is located in slots *6* and *11*. The two slots

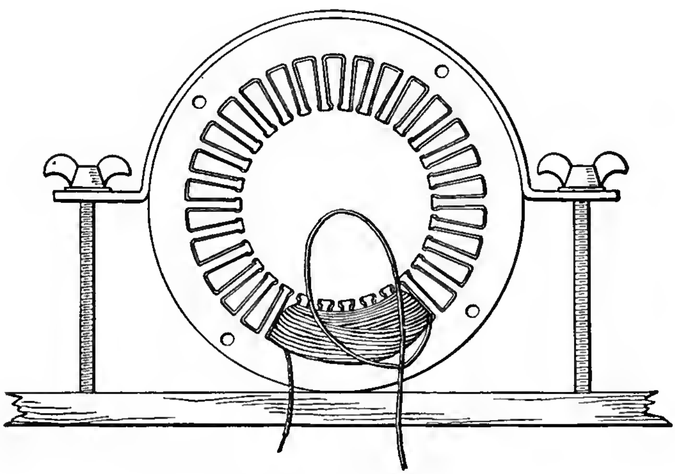


Fig. 20. Winding coil in slots by hand.

chosen on the core to represent these numbers should be located an equal distance from the two studs, or bolt holes. A piece of cotton sleeving 6 to 8 inches long is slipped over the end of the wire which forms the beginning end of the winding. The sleeving on this wire should extend at least an inch into the slot, in order to hold it in place and provide additional insulation at the edge of the core. The end of the wire with the sleeving on it is bent down over the front end of slot *6* and the wire looped at the back side of the core across to slot *11*. The wire is looped as shown in Fig. 20 and another turn placed in the same slot. The loop is usually formed by holding the wire with the right hand, while the left hand is used to guide the wire into the correct position in the slot. This process is repeated until the desired number of turns are in place, which, according to data

contained in Fig. 16, is fifteen turns. The wire is then looped in the same manner as before into slots *5* and *12*. It is not necessary to cut the wire when looping from one slot to the next, thus eliminating splices in the coil. This process of winding the wire in the slot is continued until thirty turns have been placed in these particular slots; then the wire is looped into the next slots on each side and the process continued until the winding of that group is completed. In winding the wires in the slot, care should be taken to see that they are arranged uniformly and drawn tightly in position in the slot and across the end of the core. Otherwise the winding will be bulky and there will be trouble when assembling the stator in the frame of the machine. This is especially the case when all or part of the main or starting windings are located in the same slots. In those cases where this occurs, the main winding should be confined to the bottom half of the slot in order that proper insulation can be placed on top of this winding when placing the starting winding in position.

The foregoing procedure is repeated until all the coils for a pole group—which in Fig. 16 is from slots *1* to *6* and *11* to *16*—have been wound in place. The wire is then cut off from the reel or spool, being sure to allow 6 to 8 inches for connecting to the next pole group or to the external leads. Cotton sleeving is then slipped over this lead so that it will extend back into the slot an inch or two. After the winder has had considerable experience in winding single-phase machines, the skein type of coil can be wound into the slots in the core by the same method as is used for hand winding.

Connecting Winding. The next operation, after all the coils of both the starting and running windings have been wound in slots of the core, is to connect the proper coils together. The beginning ends of the leads to the coils are usually brought out on the back side of the winding or on the bottom of the slot, while the ending ends of the leads are brought out on the inside of the winding. In Fig. 21 the beginning ends of the leads are marked OUT and the ending ends of the leads are marked IN. Thus the OUT ends of the leads are those pointing toward the outside of the stator core, and the IN ends of the leads are those pointing toward the center. In order that the current flowing through all the groups of coils in series will produce magnetic poles which have opposite polarity, it is necessary that the current flow in the opposite direction in half of

the windings. In Fig. 7 it will be noted that in passing around the rotor core the poles are alternately north and south. In Fig. 21 assume that the current is flowing into the *A* lead, and that a south pole is produced by the coil in slots *1, 2, 5,* and *6.* In the winding which is in slots *7, 8, 11,* and *12,* it is desired to produce a north pole, so the current will have to flow into the ending lead which is

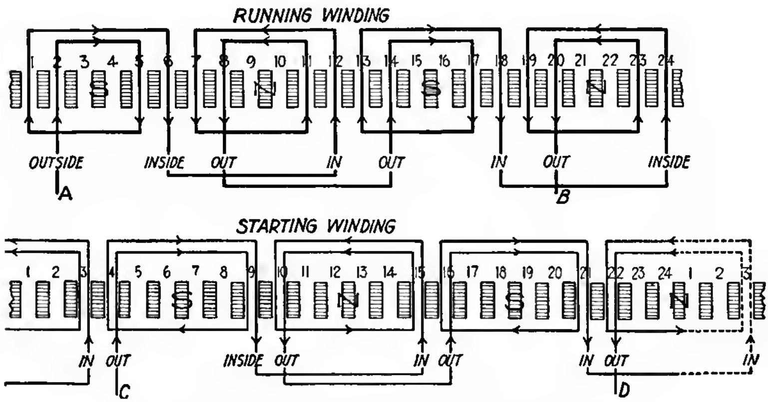


Fig. 21. Method of connecting coil groups of a single-phase motor.

marked IN. Thus the two ending ends of the adjacent pole groups of coils should be connected together. These are the two leads that are near the center or inside the rotor core. This process of connecting two inside and two outside leads together is repeated around the winding until all the coils are connected. In this particular motor there are 4 poles formed, which have polarity as shown in Fig. 21. It is assumed that the current is flowing into the *A* lead, and out of the *B* lead. It will be recalled that this method of connecting the leads is very similar to the method used in connecting the field coils on a direct-current machine in which the two inner leads of the coil were connected together and the two outer leads of the coil were connected together.

The starting winding is connected in a manner similar to the main winding. Assuming that the current is flowing in the winding at lead *C,* north and south poles will be formed, which are located three slots farther to the right than the same magnetic pole formed by the running winding. After the coil groups have been connected

together, direct current can be passed into lead *A* and out of lead *B*, and the polarity can be checked by passing a compass around the inner bore of the stator. The compass needle should indicate north, south, north, and south. The starting winding can be tested out in like manner, and should indicate similar polarity. If one of the coil or pole groups is incorrectly connected, you would have two poles of like polarity alongside each other.

The direction of rotation of a rotor can be determined by the method of connecting the windings. If the leads *A* and *C* of the running and starting winding, Fig. 21, are connected to the same line leads, the rotor will turn from the running winding toward the starting winding that has the same polarity. In this particular case, the rotor will tend to revolve from slot *3* toward slot *6*. The rule is that the rotor will turn from a running coil of a certain magnetic polarity toward the starting coil that has the same polarity. The direction of rotation of a single-phase motor can be reversed by interchanging or reversing the leads of the starting winding where they are connected with the main winding to the line wires.

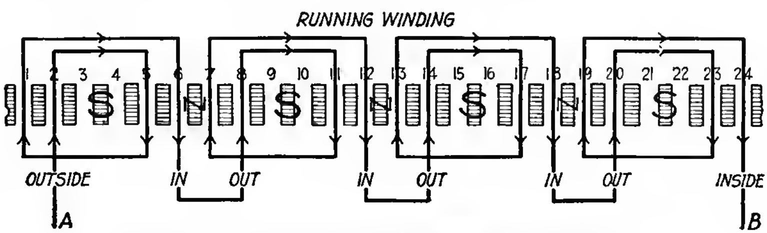


Fig. 22. Method of connecting winding for consequent poles.

Consequent Poles. In Fig. 21 the running and starting windings are shown connected for a 4-pole motor. It is often desirable to operate a motor at half this speed, in which case there would be 8 poles. In many cases where there are a small number of slots in the stator, it is not advisable to rearrange or group the windings for this number of poles. When such a condition occurs, the winding may be reconnected to take care of this connection by the "consequent-pole" method. This method consists of connecting the coils so that the current will flow through all of them in the same direction, and thus produce poles all of the same magnetic polarity, Fig. 22. These main magnetic poles, which are represented by the letter *S*, produce

consequent poles midway between them that are of opposite polarity. In connecting windings of this type, the lead on the inside of the core or winding is connected to the outside lead of the next coil as shown in Fig. 22. All the coil groups on the stator are connected together in this manner, which is the reverse of the standard or usual method. The starting coils are all connected to each other in the same manner as the running winding.

WINDING POLYPHASE INDUCTION MOTORS

Types of Windings. There are three general types or kinds of windings used on small two- or three-phase induction motors. These different windings are usually known as hand windings, basket windings, and diamond coil windings.

In many of the older makes of induction motors, the insulated wire was wound directly from the spool into the slots, in a manner similar to that described in connection with single-phase motors. The use of this type of winding is being replaced rapidly by the basket and diamond coil windings. It is used, however, to a certain extent in repairing induction motors when only one or two coils are defective, and it is not necessary to rewind the stator completely.

The basket winding derives its name from the fact that the different coils overlap each other in a manner similar to the woven parts of a basket. This will be readily seen by referring to Fig. 23. These coils are formed by winding the wire on a shuttle or pins, in a manner similar to the forming of the shuttle-type coil mentioned in the section on Winding Direct-Current Armatures. Each side of the coil usually occupies a complete slot, and thus the number of coils in a winding is equal to one-half the number of slots in a stator core. This makes it necessary that the number of slots in the stator be an even number, and that the number of slots spanned by the coil (which is the pitch of the coil) must always be odd.

The diamond coil winding is used more than any other type of winding, especially on motors of medium and large size. The method of forming this coil is the same as that described in the section on Winding Direct-Current Armatures, except that the leads are always brought out at the point of the diamond. This type of coil may be constructed so that each coil side will occupy a complete slot, or the top and bottom sides of two different coils may be in the

same slot. In the first case, the number of coils is equal to one-half the number of slots. In the second case, the number of coils is equal to the number of slots.

The majority of induction motors use a partially closed slot in which the opening is about one-half the width of the tooth. This

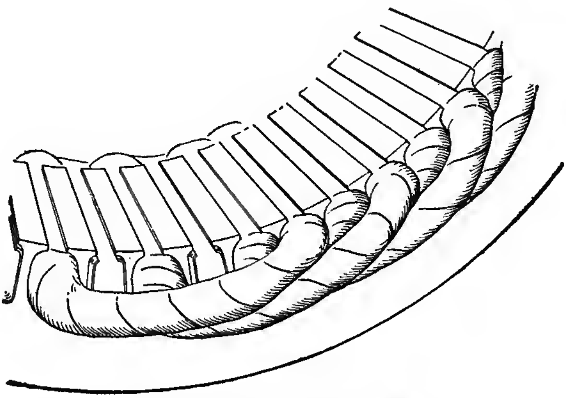


Fig. 23. Basket-type winding.

makes it impossible to tape all portions of the coil as was the case with the coils used in winding direct-current armatures. For this reason, only the end portions of the coils are taped and insulated before being inserted in the slots.

Insulating Core. The same precaution should be taken in removing burrs and sharp edges from the slots of induction motors before insulating the core as was taken with direct-current armatures. The slots of the stator are insulated in a manner similar to direct-current armatures. There is, however, a slight difference in detail, because on direct-current motors a fully insulated and treated coil is usually used. With partially closed slots, which are almost universally used on induction motors, it is impossible to insulate that portion of the coil which is placed in the slot. These slots are lined with 0.007 to 0.010-inch horn fiber or fish paper, which is cut off flush with the edges of the sides of the teeth, as shown in *A*, Fig. 24. Then a layer of treated cloth, such as empire cloth or varnished cambric, is inserted inside the horn fiber insulation and extends outside the slot approximately $\frac{1}{2}$ inch on each side in order to serve as a guide for fitting the wires of the coil into place in the slot. The thick-

ness of this treated cloth, which is often referred to as a "slot slider," is usually about the same as that of horn fiber. Thus the thickness of insulation between the core and the wires is from 0.014 to 0.020 inch, which is usually sufficient for voltages up to 250. When higher voltages are used, such as 440, it is best to use two layers of the insulating cloth.

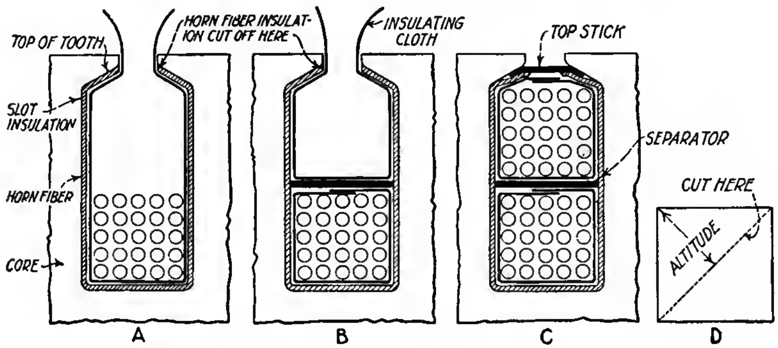


Fig. 24. Method of insulating slot and coils.

Inserting Coils in Slots. The pitch of the coil will be obtained from the winding data or engineering specifications. Assume that the data on a particular induction motor will be as follows:

phases 3	cycles 60	volts 220
r.p.m. 1150	slots 54	coils 54
coil pitch 1—7	Series Y connection	

The number of coils and slots being the same, there will be one coil per slot or two coil sides in each slot. The number of poles formed by the winding will be $60 \times 2 \times 60 = 7200 \div 1150 = 6.25$. The speed of this induction motor is rated at full-load speed, which is less than the synchronous or no-load speed. The no-load or synchronous speed would be 1200 r.p.m. and there will be 6 poles in the stator winding. The number of coils in each phase of the stator winding will be $54 \div 3 = 18$. There are 6 poles formed by these 18 coils, so the number of coils in each pole-phase group will be $18 \div 6 = 3$. Thus for this particular motor there will be 3 coils, which are connected in series with each other in a manner similar to the windings in the different slots of a single-phase motor. It is necessary to

know the number of coils in a pole-phase group before inserting them in the slots in order to know where to insert additional insulation between the ends of the coils where they overlap each other.

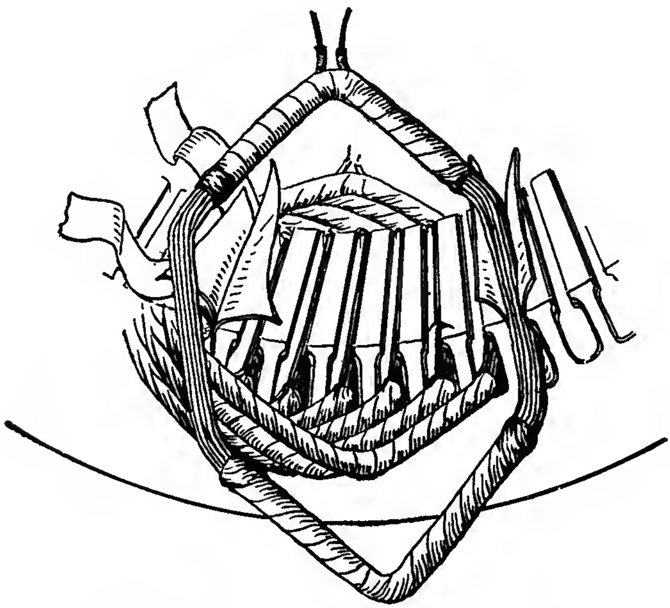


Fig. 25. Inserting diamond coils in partially closed slot.

When the diamond type of coil is used, the ends of the coil are taped, as shown in Fig. 25, and the leads are brought out near the point of the diamond. The leads are covered with cotton sleeving, which extends back into the coil about an inch or so, and in addition they are reenforced by two or three turns of cotton tape when the ends of the coil that are outside the core are taped. This manner of insulating the coil prevents dust and dirt from entering it and prevents electrical break-down and failure in service.

The untaped portion of the bottom side of the coil is flattened out at one end near the leads with the fingers of the left hand, and this end is inserted in the corner of the slot in a manner similar to that shown in Fig. 25. This coil is then pulled into position in the slot with the left hand until the taped portion of the coil is against the core, when the lead end of the coil can be dropped into place. The coil is then pushed back into correct position in the slot so

that the taped ends of the coil will be an equal distance from the core. On this particular motor the coil pitch is 1—7, so the top side of the coil will be located in slot 7. The top side of the coil is laid on top of this slot but is not inserted in the slot until the bottom coil in this slot has been put in place.

The next coils are inserted in the same manner. As soon as the bottom sides of seven coils in this particular motor have been placed in position, the top side of the seventh coil can be inserted in the slot because it is placed on top of the bottom side of the first coil. If the pitch had been 1—10 instead of 1—7, it would have been necessary to place the bottom sides of ten coils in the slots before beginning to insert the top sides of the coils. Before inserting the top sides of the coils in the slots, it is necessary to trim off the insulating cloth, shown in *A*, Fig. 24, which projects beyond the edge of the core and fold it over so that a separator, which consists of a piece of horn fiber approximately $\frac{1}{32}$ to $\frac{1}{16}$ of an inch in thickness, can be placed between the two sides of the coil. This insulating cloth is usually trimmed off by grasping both ends of it which project above the core and lifting the wires in the bottom of the slot up until they strike against the top of the teeth and cutting off the surplus insulation with a sharp knife, scissors, or a slot insulation cutter. After the insulation is cut off, the coil is forced to the bottom of the slot by gripping the two ends of the coil. The wires are arranged in order, the insulating cloth is folded over and a separator placed on top of it as shown in *B*, Fig. 24. The width of the separators should be such that they will make a very tight fit when hammered in place with a fiber block. After the top side of the coil has been inserted in the slot, the slot insulation is cut off, folded over, and forced down in the slot far enough to allow the fiber top stick or slot wedge to be inserted. It is usually necessary to hold a piece of hard fiber on the insulation directly ahead of the top stick and hammer it while the top stick is being driven into place. In many cases this insulating cloth is not cut off and folded over, in which case a separator is placed directly on top of the wires of the bottom coil and another slot slider is inserted on top of the separator. In this case the two slot sliders are trimmed off after the top coil is in place and folded over in the same manner as the top slider before the top stick is driven into

place. It is the best practice, however, to fold over the insulation of each coil separately as shown in *B* and *C*, Fig. 24.

It is advisable to provide additional insulation between two coils of different phases, especially where the voltage of the motor is over 250 volts. There are two ways of providing this additional insulation. One method is to tape one-fourth to one-half of the coils with a layer of half-lapping empire cloth or linen tape in addition to the usual cotton taping. This specially taped coil is used on the first coil of each pole-phase group. Thus if there are two coils in each pole-phase group, one-half of the coils would have this added insulation, while if there are three coils in a pole-phase group, as in the motor under consideration, every third coil should be heavily insulated. The other method of insulating the pole-phase groups is to insert a triangular piece of insulating material under the first coil of each pole-phase group. These triangular pieces of cloth are cut from a square of cloth of such dimensions that the altitude of the triangular piece is equal to the distance from the point of the coil to the edge of the core plus 1 inch. The method of cutting these pieces from squares of cloth is shown in *D*, Fig. 24.

There is a short space between the ends of the slot slider or cell and the taped portion of the coil where the only insulation on the wires is that due to the cotton covering. This portion of the coil is usually insulated by inserting a strip of linotape around the coil sides and see-sawing it back and forth until it is partly under the slot insulation. One end of this tape is then tucked in between the two coil sides and the tape is wrapped around the ends of the coil and the slot insulation several times, thus making the insulation of the coil continuous throughout. The end of this tape is inserted under the last turn and then pulled tightly in position, which will hold it firmly in place.

The inside or top leads of the coils are then bent upward and inward and the cotton insulation is removed for about an inch or more. These leads are all connected together with bare copper wire so that the coils can be tested for grounds. A testing transformer is used in applying the voltage between the windings and the iron case. The voltage to be applied in making the ground test on new windings is "two times the name-plate voltage, plus

1000 volts" and should be held on the windings for one minute. Thus for a 220-volt motor the test voltage would be $220 \times 2 + 1000$, or 1440 volts. Most of the testing transformers will give voltages in steps of 250 or 500 volts so a 1500-volt test should be applied to this motor. In case there is a ground or defective spot in the insulation, current will flow from the windings to the core and blow the fuse in the transformer circuit or open the circuit breaker. When a testing transformer is not available, the windings can be tested by using the highest voltage available. With this method the correct number of lamps should be connected in series with the test leads in order to limit the current flowing through the defective winding. With the lamps in the circuit a defect is indicated by the filament of the lamp becoming bright.

The defective coil can be located by dividing the winding into groups and testing each group and then each coil in that group until it is found.

Connecting Coils. After all the coils have been inserted in the slots in the stator, the ends insulated, and slot wedges driven in place, the next step is to connect the coils of each pole-phase group in series. The number of coils in each group is equal to the total number of coils in the stator divided by the number of poles and the number of phases. In this case, 36 divided by 4×3 equals 3. Thus there are three coils which will be connected in series with each other in order to form a pole-phase group, Fig. 26. In this figure all of the coils of the stator windings are shown. In connecting the coils, the outside end or lead of one coil is connected to the inside end or lead of the next coil, the outside end of that coil to the inside of the next, etc., thus connecting the three coils together. The inside end of the first coil and the outside end of the last coil will be used in connecting one pole-phase group to another pole-phase group. In connecting the coils into groups, it is best to start at one place and bend the inside lead of the first coil in toward the center, then bend the outside lead of that coil and the inside lead of the next coil together. The outside lead of the last coil is connected with the inside lead of the next one, and the outside lead of this coil would be bent away from the center, out of the way. This process is repeated for each of the pole-phase groups all around the stator. If an error has been made in dividing

the coils into phase groups, it would be discovered and could easily be corrected before the coils have been actually joined together.

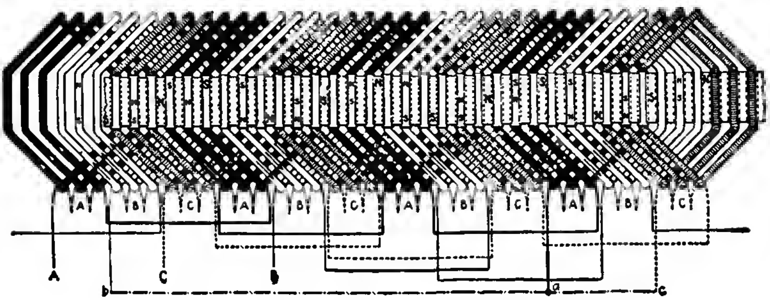


Fig. 26. Method of connecting stator coils into groups.

The next step is to remove the surplus insulation, such as the cotton covering and sleeving, from that portion of the wires that will be twisted together in connecting one coil to the next. If the copper wire is tarnished or enameled, it must be polished with sandpaper and then tinned. The process is repeated for all the leads that are used in connecting the coils into phase groups. The bared ends of the two leads are then gripped with a pair of pliers and twisted together as shown in Fig. 27. The length of the twisted portion should be about an inch, and each wire should make at least two turns about the other one. After the ends are twisted together, the winding should be checked to see that the proper number of coils have been connected together. The twisted ends are then coated with a soldering flux and soldered either with an iron or by using a small ladle and dipping the terminals in the molten solder or pouring it over them.

It is best to use a rosin flux in soldering. If an acid flux is used and any of the flux is left on the wire, it will collect moisture, which will corrode the copper wire and in time will injure the insulation. A good soldering flux which is not corrosive can be made by mixing one part glycerine, four parts alcohol, and five parts saturated solution of zinc chloride. A flux which gives good results can also be made by dissolving rosin in benzine, but it is more difficult to solder with this flux than with the zinc chloride mixture.

The ends of the wires are next cut off so that the soldered ends or stubs will be about $\frac{3}{4}$ to 1 inch in length. These stubs are insulated by wrapping them with friction or linen tape. A better and a neater job can be produced if the tape is cut into $\frac{3}{8}$- to $\frac{1}{2}$-inch

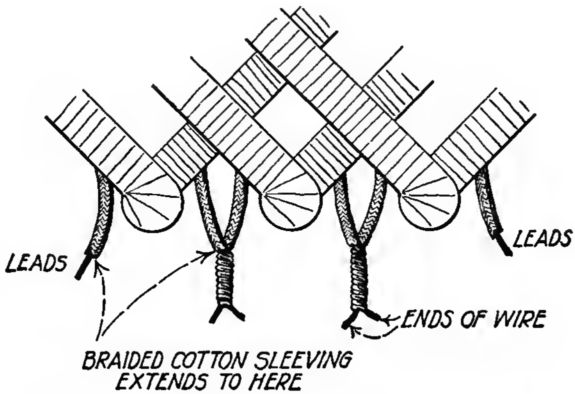
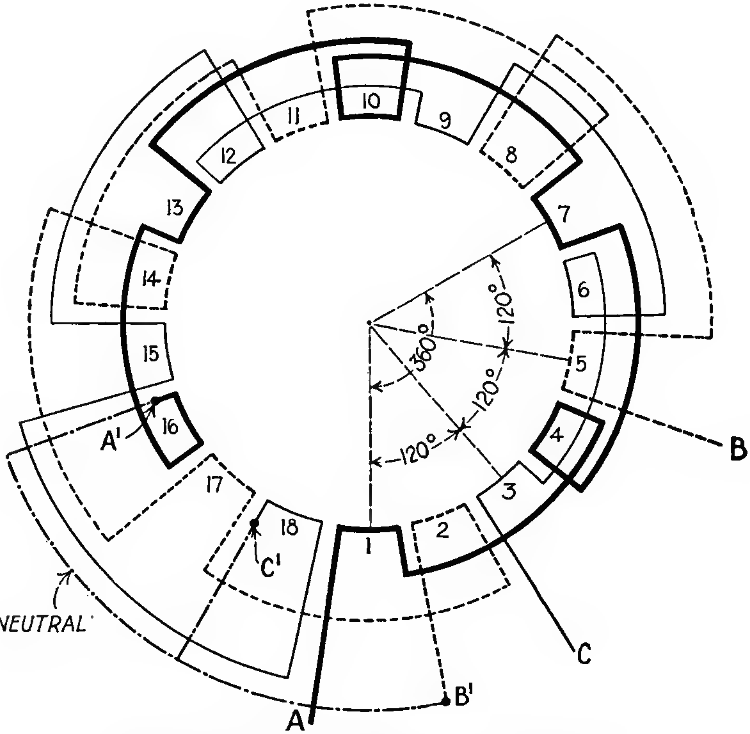


Fig. 27. Method of connecting coils into pole-phase groups.

widths instead of the standard $\frac{3}{4}$-inch width. At the present time, flexible varnished cambric tubing or sleeving is being used quite extensively instead of tape in insulating the stubs. This sleeving is easily slipped over the stub ends of the wires and when in place is cut off about one-fourth of an inch beyond the ends of the stubs. When the distance to the bearing brackets or frame of the machine is small, the insulated stubs are then bent inward between the coils so that they will not come in contact with the frame when the stator is assembled in the machine. When there is sufficient clearance, they do not need to be bent inward.

Connecting Pole-Phase Groups. The next step is to connect the different pole-phase groups together. The groups of coils of one phase can be connected so they are all in series, all in parallel, or a combination of series and parallel groupings, depending entirely upon the number of pole-phase groups in each machine. In the particular motor that we have been considering, the coils are all connected in series, as will be noted by referring to the data sheet which states, "series Y connection." One of the groups of coils near to the place in the frame where the external leads will be brought outside can be considered as phase *A*. The outside lead

from this group will be connected to the outside lead of the next phase-A group, and the inside end or lead of this group to the inside end of the next group—and so on around the armature, Fig. 26.



CONNECT A', B', C' TOGETHER FOR Y OR STAR
CONNECT A'B, B'C, C'A TOGETHER FOR △ DELTA

Fig. 28. Standard diagram for a 6-pole, three-phase, Y or Delta stator.

A standard conventional diagram for this machine is shown in Fig. 28. The coils of the phase-B group, next to the phase-A group, are not connected at this time. The coils of the phase-C group, beyond the phase-B group, are next connected in the same manner as the coils of the phase-A group. Then the phase-B group can be connected in like manner beginning with the group which is to the right of the phase-C group that was connected. It will be seen in Fig. 28 that the group of phase-B coils between those

connected to the external A and C leads is not used as the beginning of that phase winding but as the ending. This is because there are 120 electrical degrees between each of the phases, as shown in the voltage wave in Fig. 4. In an alternating-current motor or generator the electrical distance from the center of one pole-phase group to the third pole-phase group of the same phase is 360 electrical degrees, Fig. 28. In A, Fig. 29, the different phases are represented by the lines AA', BB', and CC', and the A', B', and C' ends of the phases are connected together at a point called the neutral, thus forming a Y connection.

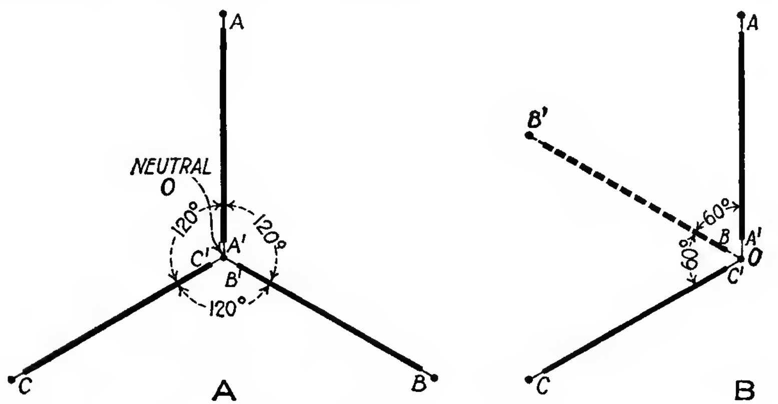


Fig. 29. Graphic representation of winding of a three-phase motor.

In case the phase-B external lead had been connected to the phase winding between the leads of phases A and C of Fig. 28, the resulting connection would be that indicated in B, Fig. 29. Thus you will see, referring to this figure, that there are only 60 electrical degrees between phases A and B and B and C. An induction motor connected in this manner would not operate satisfactorily and would soon overheat. In connecting B- and C-phase groups of coils of a three-phase motor, it is a good rule to remember to pass one phase group and start on the third and the fifth phase groups as a beginning for phases C and B. The mistake of connecting the winding in a reverse manner is frequently made even by experienced armature winders.

In making the connection from one phase group to another, it is not advisable to use cotton-covered wire, but rubber-covered or slow-

burning insulated wire of the next size larger than that used in the coils. The reason for the use of a larger size is because the heat is not radiated as fast from the rubber-covered wire as from the cotton-covered wire. When there are a number of coils connected in parallel, as will be noted by the diagrams given in the section on "Standard Induction Motor Diagrams," it is well to run four copper rings of insulated wire around the stator and tape the coil groupings to these rings. The cross-section area of the wire used in these rings should be equal to the area of the wire in the winding multiplied by one-half the number of coils connected in parallel. Thus on a 6-pole, three-phase motor where there are six groups connected in parallel, the size of the wires for the ring should be three times that of the wire used in the coil. If No. 20 wire, which has an area of 1022 circular mils, is used in the coil, it will be necessary to use No. 15 wire, which has an area of 3255 circular mils, in the ring.

After the coil groups have been connected together, soldered, and taped, and the external leads connected to the winding, the wires used in making these connections are tied securely in place with twine or cord so that they will not be injured or become caught in the revolving parts of the machine.

WINDING ALTERNATING-CURRENT GENERATORS

Small Generators. The general appearance of a small, alternating-current generator is very similar to that of a direct-current machine. The electrical connections, however, are different in that the commutator is replaced with collector rings. On a single-phase machine two collector rings are necessary; on a two-phase machine four rings are required; and on a three-phase generator three rings are used. The field coils are constructed in the same manner as for direct-current generators and there is very little difference in the mechanical construction of the frame and armature. Frequently the manufacturer uses the same armature and field punchings for an alternating-current machine that was used with the direct-current machine.

The armature coils are insulated before being placed in the slots in the same manner as described in the section on "Winding Direct-Current Armatures." Instead of connecting each coil to a commutator bar, the coils are divided into phase groups in the same manner as

for the stator of an induction motor. These different pole-phase groups are connected in a manner similar to those on induction motors. The windings on the armature are connected either Star or Delta, and the leads that were brought outside of the frame of the induction motor correspond to the leads in the armature which are connected to the collector rings. In connecting the different pole-phase groups together on the armature, it is necessary to make these connections more secure and tie the connectors more securely in place than in the induction-motor stator, because centrifugal force will tend to throw the coils outward and wreck the armature windings.

When the capacity is less than 5 horsepower, it is sometimes advisable to make the machine produce both direct and alternating current. The direct current is used for exciting the fields of the generator, which then becomes a self-excited or self-contained machine. In this case the collector rings are usually mounted on the opposite end from the commutator, and a connection is made from the collector rings to the correct points in the armature winding. In a three-phase generator the leads would be connected to points that are 120 electrical degrees apart. The majority of machines using this type of construction are either 2- or 4-pole, and the alternating current leads are connected to points that are one-third or one-sixth of the circumference of the armature. Thus with a 4-pole machine having 60 armature coils, one collector ring would be connected to armature coil No. 1, the next ring to coil No. 11, and the third ring to coil No. 21.

Large Generators. In alternating-current generators of a capacity greater than 25 to 50 kv.-a., the armature winding is placed on the stationary part of the machine the same as in an induction motor, and the field coils are placed on the revolving part called the rotor. The advantage of this is that the field coils instead of the armature coils are subjected to centrifugal force which tends to throw them out of place. It is easier and cheaper to make the field coils withstand this force than the armature coils. The armature coils and connections can be secured firmly in place on the stator much easier and cheaper than when they are placed on the revolving part of the machine. In these generators the slots are of the open type and the coils are usually insulated thoroughly by special processes before being inserted in the slots. The reason for this is because

these machines are usually operated at much higher voltage than the other machines described in this section. Special instructions, drawings, and diagrams showing how the coils are to be constructed, insulated, and connected are usually furnished by the Engineering Department to the shop for each particular machine.

INSTALLING THE ARMATURE COILS IN A 7,500 KVA SYNCHRONOUS CONDENSER, 13,200 VOLTS

Courtesy of Westinghouse Electric & Manufacturing Co., East Pittsburgh, Pa.

REPAIRING ALTERNATING-CURRENT MOTORS AND GENERATORS

Introduction. The first part of this section will take up the subject of testing the windings and the latter part will deal with repairing, rewinding, and reconnecting the windings of motors and generators. It is very fitting that the subject of testing windings should be located between those describing the winding of new machines and the repairing of old ones, because with a new machine it is about the last operation, while in repairing an old one it is the first.

It is essential that a new winding be properly tested in order to locate all defects before the motor is placed in service. The little defects can be easily removed at this time before they have a chance to damage the whole winding. It is a good practice to check and test the winding after every operation, or when each person finishes his work on the winding, for then the responsibility can be placed where it should be. The manufacturers of electric motors usually have a regular schedule of tests that must be made on the windings during each step in their construction so that they will function properly in service. In order that these tests can be made quickly and easily, it is necessary to provide special testing equipment. It is impossible for the repair man or small shop to provide the same testing equipment that the large manufacturer uses because the expense would be too great in proportion to the work done. However, there is some equipment that the repair man can build during spare time from junk materials which accumulate in the shop.

TESTING THE WINDINGS

The defects in the windings of alternating-current motors and generators can usually be grouped under five headings which are given in the order in which the greatest number occur: grounds; short-circuited coils; reversed connections; open circuits; and wrong connections. The methods described for testing and locating the

defects will apply both to a new machine that is built by the manufacturer and to repairs that are made on an old winding in the repair shop.

Grounds. The testing of the windings for grounds is done by connecting one terminal of a testing transformer to the windings and the other terminal to the frame of the machine. The test voltage applied to a new winding is usually twice the rated voltage of the machine plus 1000 volts. The test is applied for one minute. When there is considerable testing to be done, the time is shortened to one or two seconds and the test voltage is made 1.2 times that for one minute. The winding of a machine that has been in service for some time will not be able to stand the above voltage test. The test voltage for these machines should be twice the rated operating voltage. However, if several coils or part of the winding is replaced with new coils, this portion should be tested when inserted in the slots at the higher voltage, but after it is connected to the old winding, the test voltage should only be twice the operating voltage.

The windings should be tested for grounds as soon as the coils are inserted in the slots, the insulation folded over, and the slot wedges driven into place. Take a piece of bare copper wire and connect all the leads of the coils together so that they can be attached to one of the leads of the testing transformer. The other lead of the transformer is connected to the core or frame. If a ground exists, current will flow through the frame and winding from the secondary winding of the transformer. A fuse or a small circuit-breaker is located on the primary side of the transformer and this fuse or breaker will open the circuit when a ground exists between the frame and winding of the motor being tested.

The ground can usually be located by seeing a flash or small arc between the winding or core, or by a small puff of smoke, which is the result of a burned insulation. When the defects cannot be located by the above methods, the windings that are connected together by the bare copper wire should be divided into two groups and each group tested. The group that has the defect in it is divided into two more groups and tested again. This process of dividing the defective coils into two groups is continued until the defect is located. This method is the quickest and surest because in case there are two or more defects they will be discovered.

The majority of the defects due to the grounding of the windings of an induction motor occur at the edge of the core. This is often caused by bending or forcing the winding down over the end of the core at the end of the slot. The sharp edge of the end lamination of the core cuts through the insulation and allows the copper wires in the winding to touch the iron of the core. The slot wedge of this slot and one or two slots on either side of the defective coil should be removed so that the defective coil can be lifted or raised out of the slot for repairs. When a portion of the coil inside the core is not taped or insulated before being placed in the slot, as is often the case with partially closed slots, the defect can be repaired by inserting additional insulating material between the core and winding. This additional insulation should be of such size that it will extend at least an inch beyond the burned spot on the original insulation. The wire of the coil, where the ground occurs, should be examined to see that the arc produced between it and the core by the testing transformer did not injure the wire or reduce its cross-sectional area. If the wire is burned or melted away at this point enough to reduce the area to three-quarters of the area of that size wire or conductor, the coil should be replaced with a new coil. If this is not done, the wire will overheat at that point and in a short time the insulation will burn and the winding will either be grounded or a short circuit will be formed between several turns of the coil. These few turns will heat very rapidly and if the motor is operated for any length of time in this condition, the whole motor winding will burn up.

When a ground occurs on a coil that has been taped or treated before being placed in the slots, it is best to either remove the coil or to raise up that side so that the burned insulation can be removed and the portion of the coil retaped and insulated or treated with insulating varnish. The burned spot should be examined to see that the arc between the wires and core did not injure the insulation between adjacent turns. If it appears that the insulation between turns is injured, it should be strengthened by inserting small pieces of treated or varnished cloth between the adjacent turns.

The windings of the machine are tested again for grounds after the coils have been connected together in the proper manner. The final ground test is made after the machine has been completely

assembled and given a shop or heat test. It is seldom that a ground will show up on the later tests unless the winding is injured in the shop or during assembly, especially if any defects that developed and appeared on the first test are properly repaired.

Testing Transformer. The transformer used for applying a voltage test to the windings in order to locate grounds can be purchased from a manufacturer of transformers, or it can be built when the necessary materials are available in the shop. A small 500-watt bench type is very handy for the armature winder and repair man as it can be easily carried from one place to another and set on the bench near the work. When there is only one transformer in the plant or shop, it should be of a larger size, usually of a one- or two-kilowatt capacity.

The dimension and construction of the core for a one-kilowatt transformer is shown in Fig. 1. The transformer core is composed of a No. 26 U.S. gage (0.019 inch) sheet steel of the same quality as is used in the cores of armatures. The sheet steel is cut into strips that are 11 and 17 inches long and 2 inches wide. Half of these strips are dipped into thin insulating varnish and dried before assembling in a core. When the core is assembled or stacked, a layer of the laminations are arranged as in *A*, Fig. 1, and the next layer with the varnished strips are arranged as in *B*. The next layer, which is not varnished, is arranged as in *A*, and this process of arranging the layers and having every other one varnished is continued until the core is completed. The reason for arranging the laminations as shown in *A* and *B* is to break the joints and form a solid core that will allow the magnetic lines of force to pass through it easily. The purpose of using the varnished strips is to keep the laminations from making metal contact and thus prevent any electrical current from flowing from one lamination to another. These electrical currents are usually called eddy currents.

The core is clamped by the pieces of angle iron and bolts, as in *C* and *D*, Fig. 1. A piece of pressboard or fiber is inserted between the core and the angle iron braces. They are put on after the coils are in place. The sides of the core where the coils are located are taped with half-lap cotton webbing or tape, which is wrapped on as tight as possible in order to hold the laminations in place when the coil is being wound on the core. The clamps and the laminations

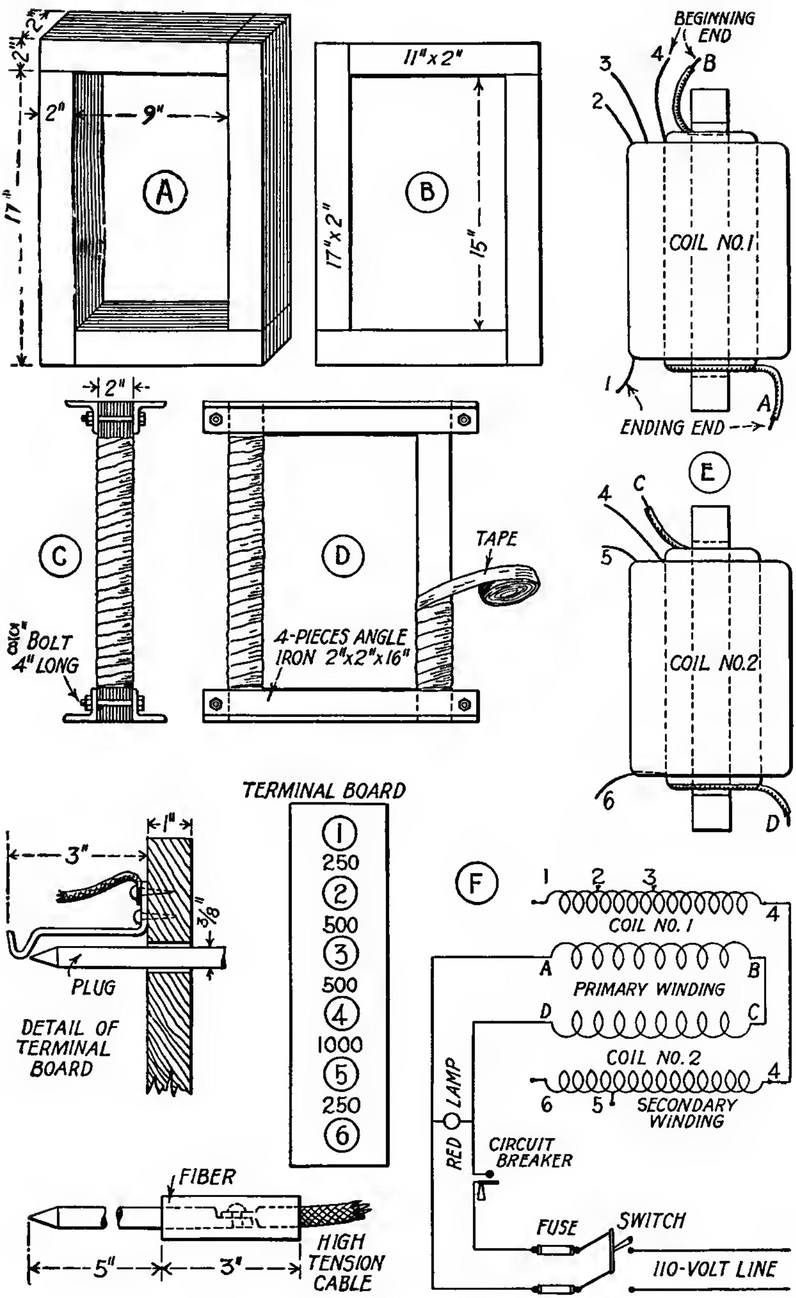


Fig. 1. Details of Testing Transformer

under the clamps are removed in order that the taped core can be fastened in a lathe or winding machine and the coils can be wound on the core.

The core is insulated with one layer of 0.030-inch pressboard, one layer of 0.010-inch flexible mica or empire cloth, and one layer of 0.020-inch horn fiber. The material should be arranged so that joints of the different layers do not come opposite each other, but each sheet will go around about one and one-quarter times. The electrical data for the winding of the transformer is given below.

PRIMARY WINDING

Primary voltage	110
Number of turns	516
Number of turns per coil	258
Size of wire	No. 8 D. C. C.
Coil composed of	3 layers of 86 wires each

SECONDARY WINDING

Secondary voltage	250 to 2500
Number of turns	11740
Number of turns per coil	5870
Size of wire	No. 23 D. C. C.

Coil No. 1 composed of 2346 turns, 6 layers of 391 turns to tap No. 3.
Coil No. 1 composed of 4692 turns, 12 layers of 391 turns to tap No. 2.
Coil No. 1 composed of 5870 turns, 15 layers of 391 turns to tap No. 1.
Coil No. 2 composed of 4692 turns, 12 layers of 391 turns to tap No. 5.
Coil No. 2 composed of 5870 turns, 15 layers of 391 turns to tap No. 6.

The same amount and kind of insulation should be used between the primary and secondary windings as was used between the core and primary windings. One layer of 0.010-inch empire cloth should be placed between each layer of wires on both the primary and secondary coils. The leads for the terminals and taps of the secondary coils should consist of No. 12 or 14 lamp cord soldered to the solid wire in the coil. The lamp cord, being composed of a large number of small wires, is very flexible and can be bent without danger of breaking.

The two primary coils are connected in series by connecting the leads *B* and *C* together as shown in *E* and *F*, Fig. 1. All the coils are wound in the same direction and the leads and taps of the secondary coils are connected as shown in the wiring diagram. The connections are made as shown in the detail on the back of the terminal board. The leads marked 1, 2, 3, etc. are connected to the

corresponding numbered terminals on the back of the board. Connecting the terminals on the back of the panel provides a safe installation for they cannot come in contact with the high-tension wiring. The two testing leads that connect to the plugs which fit in the terminal board are 10 to 15 feet in length and are composed of high-tension rubber-covered wire such as is used in wiring spark plugs on an automobile. The numbers between the holes on the terminal board in *F*, Fig. 1, indicate the voltage that exists between them. When it is desired to obtain 250 volts, the plugs can be inserted in holes 1 and 2 or 5 and 6. Likewise, for 1500 volts, the plugs are inserted in holes 3 and 5; for 2500 volts, the plugs are inserted in holes 1 and 6.

The transformer, terminal board, circuit breaker, and switch can be mounted in and on a box that can be pushed from one place to another. The red lamp, which is connected across the terminals of the primary winding, should be mounted on top of the box so that those working about the transformer will know that it is in use. The circuit breaker will open the circuit when a defect develops in the apparatus being tested. It can be closed much more quickly than a fuse can be replaced. The fuses at the switch are for protection in case the circuit breaker fails to operate. In installations where the transformer is not used very often, a renewable fuse may be used in place of the circuit breaker.

Short Circuits. A short circuit is caused by two wires coming in contact with each other, providing a shorter path having lower resistance than the designed path. The current through any short circuit can be found by applying Ohm's law, which states that the current is equal to the voltage divided by the resistance. When two copper wires come in contact with each other, the contact resistance will be very low, usually less than 0.01 ohm. If the voltage produced by the coil, or turn, that is shorted is only one volt, the current that will flow through is $1 \div 0.01$, or 100. This is a very large current for the usual size of wire used in medium sized motors. This current will soon heat the wire to a temperature which will melt the insulating compound out of the windings. If the machine is not stopped at once, the insulating material will be burned.

When one of the turns on the coil comes into contact with another turn and forms a short circuit, Fig. 2, the current supplied

to the motor from the line does not flow through all the turns, but a part flows through the short circuit to the next turn or coil. This short-circuited turn is an idle coil, which acts as a generator and produces voltage, because it is cut by the lines of force produced by the rotating magnetic field.

The current will enter the short-circuited coil at *A*, Fig. 2, and flow through the sides of the coil numbered 1, 11, and 2, through the spot where the bare wires touch each other, as at *X*, through 13 and out of the coil at *B* as shown by the heavy arrows. A voltage is produced in the coil sides 3 and 12, due to the magnetic lines of force in the iron changing as the current flowing from *A* to *B* changes in different parts of the cycle. This voltage causes a current to

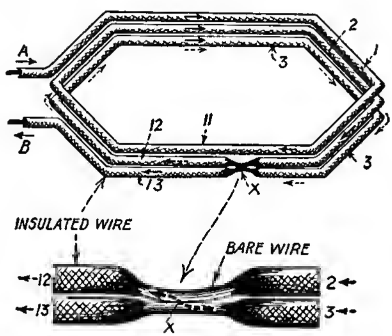


Fig. 2. A Short-Circuited Stator Coil

flow through conductors 3, *X*, and 12, and back to conductor 3, as indicated by the dotted arrows, Fig. 2. The current in this coil can easily be from two to ten times stronger than the current flowing through the rest of the coil. The result is that the wire becomes very hot in a short time.

There are several methods that can be used to locate a coil that has one, several, or all of its turns short circuited. The greater the number of short-circuited turns in a coil, the sooner it will heat and make itself known. When the stator winding is assembled in the motor, it can be tested by running the motor without any load for from ten to thirty minutes and observing the temperature of the ends of the coils with the hand as soon as the motor is stopped. The temperature of all the coils should be the same. If one or two of the

coils are much warmer than the others, it would indicate that they are short circuited.

A short-circuited coil can be located in the stator winding by using the growler in the same way as on direct-current armatures.

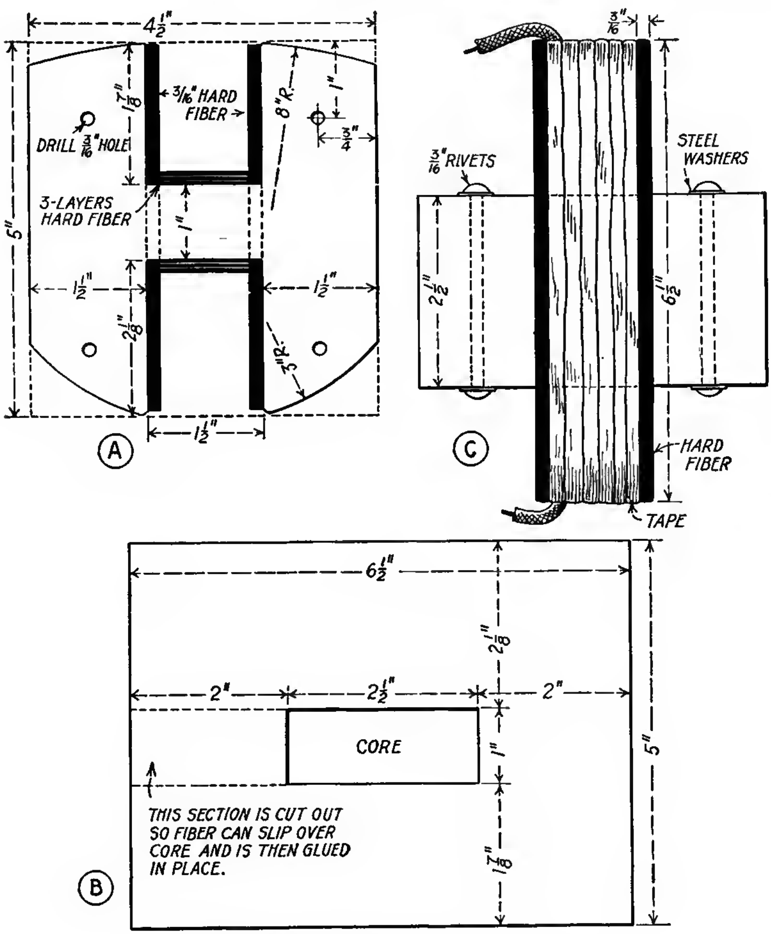


Fig. 3. Details of Growler for Testing Stator Coils

The shape of the growler should be convex, Fig. 3, instead of concave The radius of the curvature of the growler should be about the samc as the inside of the stator laminations. The other side of the growler can be made to a different radius so that it can be used on another

size stator. The amount of current required to operate a growler is reduced considerable when the contact surface, or area, of the growler that is in contact with the stator laminations is increased. The reason for this is that iron is a better conductor of the magnetic lines of force than air. The current required to operate the growler can be decreased by winding more turns on the coil, but this also reduces its ability to detect a short-circuited coil.

Constructing Growler. The growler, Fig. 3, is constructed from sheet metal laminations that are cut to $4\frac{1}{2}$ by 5 inches, as indicated by the dotted lines, and stacked in a pile. Three-sixteenths inch holes are drilled for the rivets. There should be enough of the laminations so that they will make a pile $2\frac{1}{2}$ inches high when they are clamped tightly together and riveted. The laminations should be clamped by hand or by a hydraulic press when available in order to obtain a solid and well-built growler. Another method is to use a wooden or steel beam or bench vice for clamping the laminations while they are being riveted. A steel washer should be placed on each end of the rivet in order to secure greater bearing surface on the laminations. Cut the space for the coil and round off the edges of the laminations to the radius shown at *A*, Fig. 3. This can be done with a hack saw and the sharp corners smoothed up with a fine file. The edges of the core, where the coil is located, are rounded off so that they will not cut through the winding and cause a short circuit in the coil. A strip of 0.007- to 0.010-inch flexible horn fiber or fish paper is wound three times around the core of the growler. The two pieces of $\frac{3}{16}$-inch hard fiber shown at *B*, Fig. 3, which insulate and support the sides of the coil, are placed in position as shown at *A*. It is necessary to cut out a section of the fiber in order to place it on the core, and this piece should be glued in place and can be made stronger by glueing a piece of $\frac{1}{32}$-inch horn fiber to the outside of the $\frac{3}{16}$-inch fiber after it is in place.

The growler should be wound with about 250 turns of No. 16 double-cotton covered wire when it is to be operated from a 110-volt alternating-current circuit. A piece of No. 14 rubber-covered wire with stranded conductors should be soldered to the end of the No. 16 cotton-covered wire, because it is more flexible and not as easily broken as a solid wire. This rubber-covered wire should form the first turn on the core of the growler. In winding the coil, it is

desirable to insert a layer of paper or empire cloth between every four or five turns in order to improve the insulation on the coil. When the desired number of turns have been wound on the growler, a piece of the rubber-covered wire is soldered to it to form the external lead. The coil is dipped or painted with insulating varnish

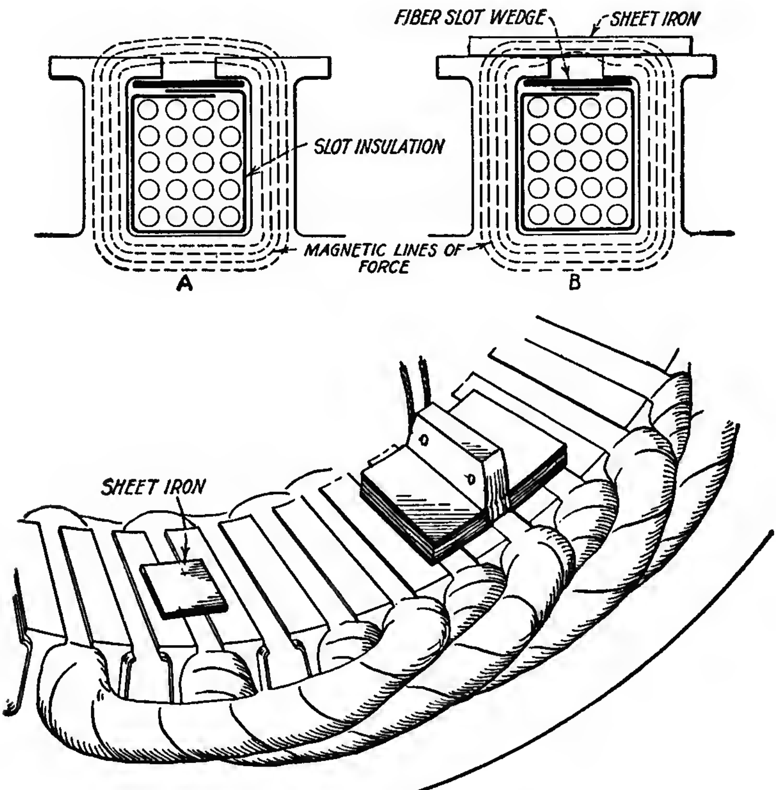


Fig. 4. Method of Using Growler

or compound, and then cotton or friction tape is wound tightly over the core in the same direction as the wire to protect it from injury.

Action of Growler. When the growler is placed over a coil in the stator, Fig. 4, and the current turned on, a voltage is induced in the coils in the slots due to magnetic lines of force passing from one

side of the growler to the stator teeth, through the coils in the slot to the teeth on the other side of the slot, and into the growler. The action of a growler is the same as that of a transformer. If the windings of the stator are free from short circuits, there will not be any current flowing through these windings because the circuit is open. If, however, the winding has a short-circuited turn, or coil, in it, a current can flow through this turn, or coil, because there is a complete electrical circuit. The amount of current flowing will depend on the voltage induced by the growler and upon the resistance of the circuit. The current flowing in the short-circuited coils produces magnetism or lines of force which oppose those produced by the growler. This opposition causes the growler to take more current, which would be observed if an ammeter was connected in the circuit. Thus an ammeter could be used to detect a short-circuited coil.

It is not necessary to go to the expense of using an ammeter because the short-circuited coil can be easily located by passing a small piece of sheet iron or steel over the slots in which the other side of the coil, that is under the growler, is located, Fig. 3. If there is a short circuit in that coil, the piece of sheet iron will be attracted to the stator core at a point directly over the short-circuited coil. This is due to magnetic lines of force being set up around the coil, as shown at *A*, Fig. 4. These lines of force pass from one tooth, through the core, to the tooth on the other side of the coil, and then through the air to the first tooth. A piece of sheet iron, or steel, will easily provide a better path than air, and the lines of force will tend to pass through this piece of iron or steel, as shown at *B*, Fig. 4. This causes the piece of steel to be drawn to the core. When there is one side of two coils in the same slot, as is often the case on most induction motors, a piece of sheet steel should be passed around the core on both sides of the growler. The growler should then be moved so that it will be over the next coils and the core again tested with the piece of iron. This process is kept up until the growler has been over all the coils and the opposite side of the coil has been tested.

The growler is very useful in locating short circuits in a coil or in locating a complete short-circuited coil. It is not as good in locating a complete short-circuited pole-phase group, because it

does not induce a high enough voltage to cause a current to flow through the pole-phase group and produce enough magnetism that will attract a small piece of sheet iron. If the growler was strong enough to attract the piece of iron, there would be an attraction over all the sides of the coils in that pole-phase group. A short-circuited pole-phase group is usually caused by a mistake in connecting the windings and is very easily detected when the winding is tested for reversed coils with a compass. The same is true when one phase is completely short-circuited due to wrong connection.

Reversed Connections. Reversed connections in the winding may be caused by a reversed coil, a reversed pole-phase group, or a complete reversed phase. These defects can sometimes be located by a careful inspection and checking of the connections, but it is better to test the windings and locate the defect with a compass.

Compass Test. The compass test will locate a reversed coil, a reversed pole-phase group, a reversed phase, a short-circuited pole-phase group, and a short-circuited phase. It is necessary to use direct current for this test, because with alternating current the direction of flow changes so rapidly that the compass needle cannot follow the changes. If there is a source of direct current in the shop, all the equipment needed will be a rheostat, which will limit the current to a safe value, and an ordinary pocket compass. When direct current is not available, an ordinary 6-volt automobile battery can be used. A rheostat will not be needed with a battery because the current can be regulated by increasing or decreasing the number of cells used. It is necessary to use only enough current to strongly attract the compass needle to the core.

The majority of machines built today are three-phase and their windings may be either star- or delta-connected. In making this test, the three external leads from the motor are marked or designated *A*, *B*, and *C*, or they can be marked I, II, and III with chalk, or a small notch can be cut in the insulation of the wire on the lead near the end that is not connected to the windings. Likewise, one of the direct-current leads should be marked and considered positive. This lead is attached to the *A* lead of the stator winding and the other direct-current lead is attached to the *B* lead. Current will now flow through the windings of A-phase and B-phase, as shown by the arrows, Fig. 5, which is a complete winding diagram for a 3-phase

4-pole series star-, or Y-connected, machine having 36 slots and 36 coils. The polarity of the poles, as indicated by the compass, is shown by the heavy letters **S** and **N,** which are near the bottom of the core. This polarity should be marked on the core with chalk.

The two direct-current leads are removed and the positive, or marked, lead is connected to the *B*-lead of the machine and the

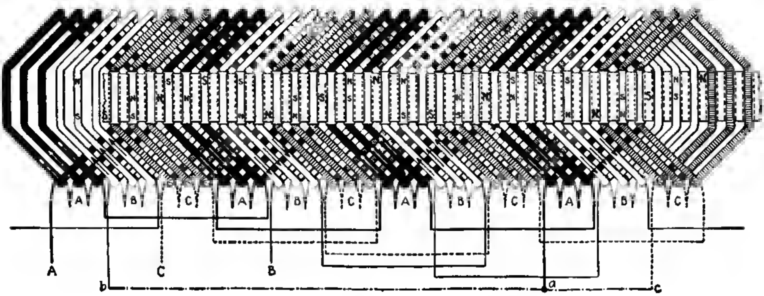


Fig. 5. Magnetic Polarity of a Correctly Connected Stator

other direct-current lead is connected to the *C*-lead. Current is passed through the windings and the polarity, as indicated by the compass, is marked on the center of the core in the same manner as before. The leads are disconnected and the marked, or positive,

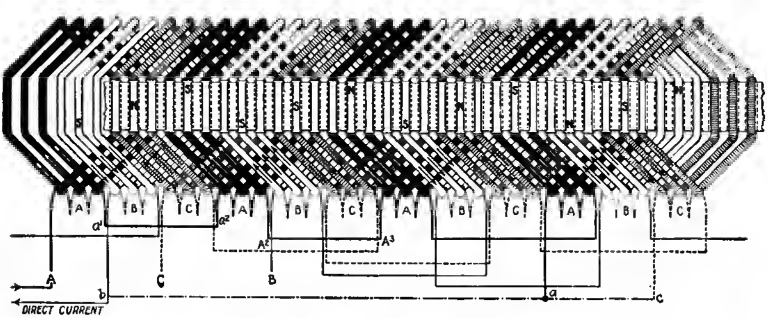


Fig. 6. Magnetic Polarity with a Reversed Pole-Phase Group of Coils

lead is connected to the *C*-lead and the other direct-current lead is connected to the *A*-lead. The polarity is marked at the top of the core.

The polarity marks on the core will resemble Fig. 5 and will be **N, S, N, S,** etc., on around the winding. This indicates the correct

polarity and shows that the winding has been correctly connected. The polarity would be the same for a delta-connected winding as for a star connection.

When the polarity of the windings, shown in Fig. 6, are tested by passing current through them, it is observed that the polarity of the three phases are **S, N, S, S, S, N, S, N, S, N, S,** and **N.** It is seen at a glance that one of the pole-phase group of coils is reversed because there are three south poles together. In order to determine in which phase the reversed group is, the polarity of each phase should be observed. Thus for phase *A*, the polarity is **S, S, S,** and **N,** which indicates that the second pole-phase group is the one that is reversed. If the polarity of the second pole-phase group is changed by reversing, the connections of this group would read **S, N, S,** and **N,** which is correct. Comparing the connections of the winding in

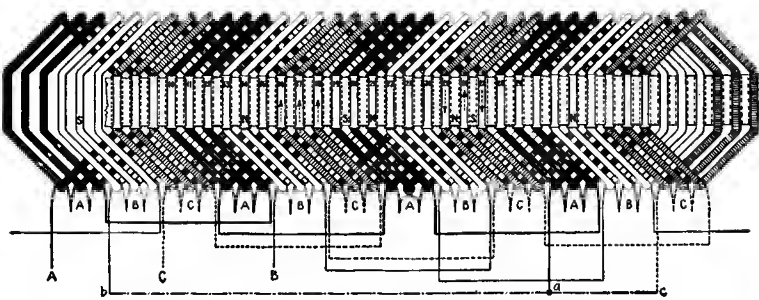


Fig. 7. Magnetic Polarity with a Reversed Coil

Fig. 6 with the correct diagram in Fig. 5, it is seen that the second pole-phase group of phase *A* is the one that is not correctly connected. The correction can be made by connecting *a*1 to *A*2 and *a*2 to *A*3. In testing the winding, Fig. 6, one test lead is connected to the neutral, while the other lead is connected first to *A*-phase, then *B*-phase, and then to *C*-phase. The connections can be made as in Fig. 5 if desired and the result and polarity will be the same.

It is not as easy to locate a reversed coil in a phase group by the compass test as it is to locate a reversed pole-phase group. The direction of the flow of current through the windings, when there is a reversed coil in the third pole-phase group of phase *A*, is shown in Fig. 7 when direct current is being passed to the *A* lead of phase

A, and the compass is slowly passed over the stator core, the needle will gradually change from south to north, then slowly to south, etc. The direction that the compass needle points when held over slots numbers 10 to 23 is indicated by the short arrows above the slots, Fig. 8. The dotted lines and the arrows indicate the direction of flow of the magnetic lines of force produced by the direct current in the winding of phase *A*. In Fig. 8, which is an end view of the windings in the slots, the compass needle points horizontally when above slot 11, and it gradually assumes a vertical position when it is passed over slot 14, which is a north pole. It attains a horizontal position at slot 17 and changes rapidly to a downward position

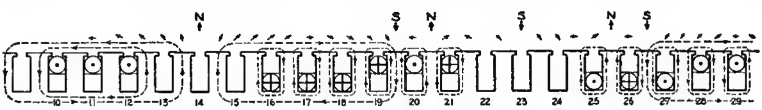


Fig. 8. Direction of Magnetic Lines of Force Produced by a Reversed Coil

between slots 19 and 20 and then rapidly reverses and points upward between slots 20 and 21. As the compass is passed on over slots 21 and 22, the needle changes from a vertical position to a horizontal and then down when it passes over slot 23. The rapid change of the needle as the compass is passed over slots 19, 20, and 21 indicates that there is a reversed coil and the connections of the coils of this particular winding in these slots should be inspected closely. This indicates that the coil of phase *A* winding in slot 20 is reversed. This coil should be reconnected so that the compass needle will change gradually as from slots 11 to 17. This same condition of the compass needle will be observed when it is passed over slots 25, 26, and 27, as when it is passed over 19, 20, and 21, because the other side of the coil is located in these slots.

When there are only two coils in each pole-phase group, the effect of a reversed coil would be more noticeable than when there are three, four, or more coils. This condition is more easily discovered with a small direct current than with a very heavy current. A very heavy current will produce more magnetism than can be carried by the core and these lines of force pass through the air and affect the compass when it is held some distance from the core. The magnetism from the reversed coil does not pass out into the air as far as that

from the other coils, so the compass is affected almost entirely by the good coils.

Reversed Phase. A reversed phase in a three-phase winding can be detected by the compass test. With a reversed phase, the polarity would be **S, S, S, N, N, N, S, S, S, N, N,** and **N,** Fig. 9. This shows that the middle one of the pole-phase groups has the reversed polarity because the polarity of a correct winding would be **S, N,, S, N,** etc. as shown in the preceding tests. With the Y-, or star-connected winding, this error, or defect, is remedied by disconnecting the end of the second or B-phase from the neutral connection and connecting an external lead to this end of the phase winding.

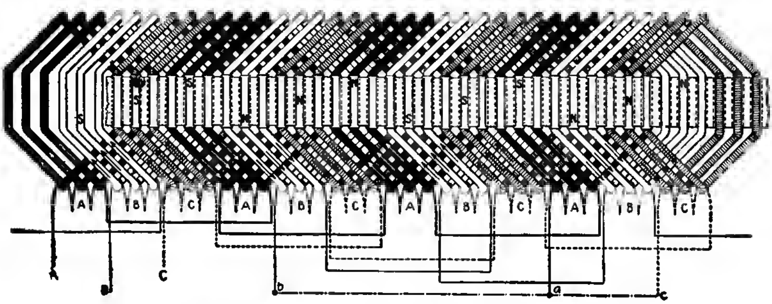


Fig. 9. Magnetic Polarity with a Reversed Phase

The other end of the phase winding would be connected to the neutral connection. In a delta-connected winding, this defect is repaired by disconnecting the ends of the reversed phase and connecting the opposite ends to the other two phases.

A reversed phase connection on a two-phase winding would cause the motor to run in the opposite direction. The rotation of the motor can be easily reversed by interchanging or reversing the two leads of any one of the phases.

A reversed phase can be easily discovered when the motor is running without a load, because it will run at a much lower speed (if it runs at all), emits a loud growling noise, and will soon become very hot. This defect can also be detected with the same apparatus used in determining if the three phases are balanced.

Balance Test. The balance test determines if there are the same number of coils in each phase. This test can be made with an

alternating-current ammeter. The alternating current must have a voltage about one-fifth the rated voltage of the motor. With a star-connected winding, one lead of the low-voltage alternating-current circuit is connected to the neutral point and the other lead of the low-voltage circuit is connected to one of the phases. The ammeter is connected to one of the leads and the current taken by the different phases is obtained by changing the low-voltage lead from one phase to another phase. The ammeter should read the same in all three phases. With a delta-connected winding, it is necessary to open up the connections at one of the corners of the delta and connect the low-voltage leads to the end of the windings of each phase. The current taken by each phase is obtained by changing the connections from the ends of one phase to the next.

A "balance-coil" tester can be very easily constructed with the materials usually found in the average repair shop and can be used in place of the ammeter, Fig. 10. The materials required are No. 22 soft iron wire and No. 18 double-cotton enamel-covered wire. The No. 22 wire is straightened and cut into lengths 14 inches long and assembled into a core until the diameter is about one inch. The wires can be bound tightly into a bundle by wrapping them with a layer of cotton tape that is half lapped and wrapped as tight as possible. The cotton tape is brushed with air-drying insulating varnish, or shellac; and when this is dry, a layer of 0.007-inch empire cloth is placed between two layers of 0.005-inch pressboard, or fish paper, and wrapped around the core. Then one layer of No. 18 double-cotton enameled-covered wire is wound closely and tightly on the core from one end of the wooden end blocks to the other. The ends of the wire leading from the coil should be about 6 inches long and insulated with cotton or varnished cambric sleeving. A layer of empire cloth is wrapped around the coil and the second layer of insulated wire is wound on the core, beginning at the end of the coil where the first layer ended. Another layer of empire cloth is wrapped around the coil and the third layer is wound in place. As soon as a layer of wire is wound on the core, insulating varnish or shellac is applied with a brush so that a solid coil will be formed. The ending end of the top or third layer is connected to the ending end of the first layer and the connection is soldered. The beginning end of the first and second layers are connected to binding

posts *A* and *B* that are fastened to the board forming the base of the tester. When the insulating varnish on the top layer of the coil has dried, a strip of insulation about one-eighth to one-quarter of an inch in width is removed from the top of the wires for the full length of the coil. The wires in this strip should be polished with sand paper so that they are bright in order that good electrical

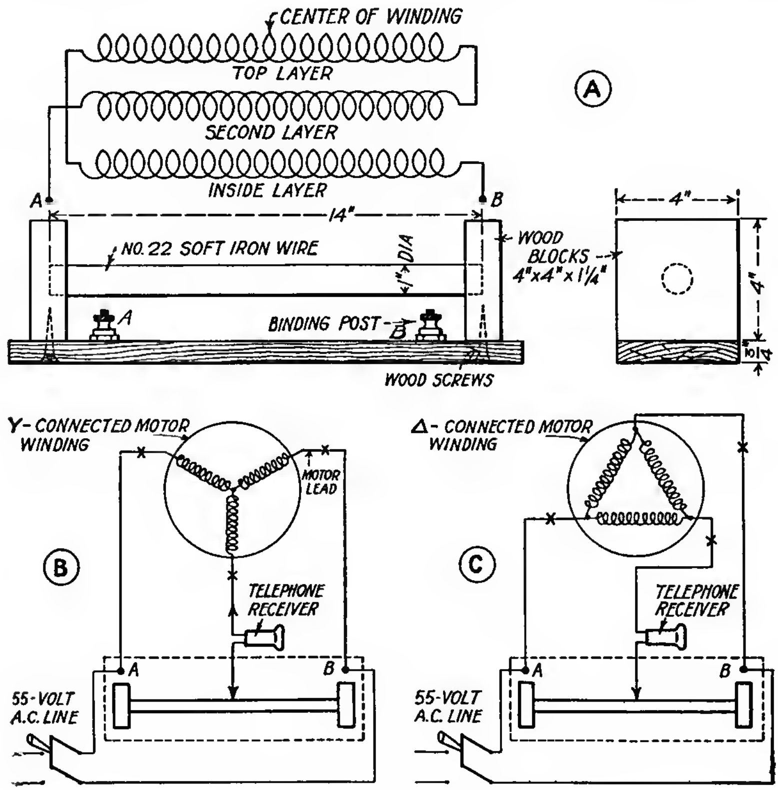


Fig. 10. Details of "Balance Tester"

contact will be made when the tester is used. The center, or middle, turn of the top coil should be located and marked by painting a colored band around the coil at this point.

The method of connecting and using the tester is shown at *B* and *C*, Fig. 10. The single-phase alternating current is connected to the terminals *A* and *B* of the tester. One lead from the winding of the three-phase motor is connected to terminal *A* and another

lead of the motor is connected to *B*, while the third lead is connected to a telephone receiver. The other terminal of the telephone receiver is touched to the bared wires of the outer coil when the switch is closed. If the winding is correctly balanced, there will not be any sound in the telephone receiver when the wire from the receiver is touched to the center point of the upper layer of the winding on the tester coil. If a click is obtained in the receiver, various points to the right and left of the center should be touched with the lead from the receiver until a point is obtained where there is no sound.

When the stator winding has been correctly placed and connected, the point where no sound is heard in the telephone receiver should not be more than four or five wires from the center point on the coil. If the point is greater than this amount, it indicates (1) that one phase of the winding in the motor has a great number of turns of wire in the winding, which may be due to a mistake in the number of turns of wire in one of the coils or in several; (2) a mistake in the number of coils connected in each phase; (3) a short-circuited coil; (4) a reversed coil; (5) a reversed pole-phase group; or (6) a reversed phase.

While the balance tester is not designed or intended to locate any particular defects, it makes an ideal device for determining if the connections are correct. This device proves very useful in checking the connections of the coils and pole-phase groups before they are soldered and for checking the tests made with the compass or growler. It is the usual practice to have another winder check the connections with the diagram before they are soldered and this work requires more time than to make the balance test. This test is often applied after all connections have been soldered and the winding dipped in insulating compound and baked, as it will show quickly if any damage to the windings has occurred while the stator was being handled after being wound.

The balance tester with the windings, Fig. 10, is intended to be used for testing induction motor windings designed for 110, 220, or 440 volts. The 55-volt alternating current is obtained from a 110-volt alternating-current line by using a step-down transformer having a ratio of 2 to 1 or by the use of an autotransformer. When the motor winding is for 220 or 440 volts, 110 volts can be used for testing, providing the tests are made very quickly and the current

is not kept on for more than a minute. If the current is kept on for much longer, there is danger of overheating the motor winding and damaging it. The balance coil will heat very rapidly, but there is less danger of damaging it than the motor winding because the heat of the coils radiates easily to the air.

Wrong Connections. *For Voltage.* This error can be made by connecting the pole-phase groups of each phase in series instead of parallel or the reverse. For example: The winding on a 440-volt motor may be designed so all the coils and pole-phase groups should be connected in series. By mistake, they are connected so that there are two paths, or circuits, in parallel instead of one. If the motor is connected to a 440-volt line and run without load and the current taken by it is measured with an ammeter, it will be found that the current is nearly as great as the full-load current for that size motor. There will also be a very loud magnetic hum and vibration which shows that the magnetism produced by the current in the windings is much greater than it should be. This is because the voltage forcing the current through the windings is twice that for which they were designed.

If a winding is connected so that there are a greater number of coils in series than for which the winding is designed, it is indicated by the current being much less than what it should be for that size motor when it is running idle. When a motor with this connection is being tested by connecting a load to it, it will easily pull out of step and stop when the load is much less than it should be. The stopping of an induction motor due to applying too much load is usually called the "pull out." The point at which this occurs in correctly designed and connected motors is when the motor is delivering two to three times its full load torque.

The majority of wrong connections for voltage is due to getting twice or else only half the correct number of turns or coils in series in each phase. This trouble is usually due to the wrong number of pole-phase groups being connected in series and can be remedied by reconnecting the pole-phase groups.

For Speed. This error does not occur very often and is usually found when the motor is given a test run to determine the no-load current taken by the motor. When the motor is running without load, the speed can be determined with a speed counter. When

making this test, if the alternating current is supplied by a generator in the plant, be certain that the frequency is up to standard. This is very important especially if the current is supplied by a motor-generator set that is operated by a direct-current motor. There is a tendency for the speed of the direct motor to decrease as more load is placed on the motor being tested, and this will decrease the frequency of the current produced by the alternating-current generator. This in turn will cause the speed to be much less than that shown on the nameplate. When the current used for testing is supplied by a large power company or central station, it is not necessary to check the frequency, because it is very seldom that it changes or deviates from the standard by more than one cycle per second.

The cause of incorrect speed may be due to wrong connections. In this case, the speed will be considerably different from the name-plate speed, especially if the speed is between 900 and 1800 revolutions per minute. This is because the motor has been connected for the wrong number of poles. This defect should have been detected when the winding was given the compass test. The remedy is to reconnect the winding for the correct number of poles. A table showing the motor speeds for 25-, 40-, and 60-cycle motors having from 2 to 24 poles is given in the next section.

LOCATING MOTOR TROUBLES

Hot Bearing. A hot bearing will make itself known in several ways, the most prominent of which are smoking and a high-pitched screeching sound, which is readily recognized by those operating electrical machinery. This is caused by lack of oil, failure of the oil rings to revolve with the shaft, and by dirty or gritty oil. The oil rings should be watched and, in case they do not revolve properly on the shaft, they should be replaced with new ones.

A hot bearing is sometimes caused by a shaft being out of true or by a bearing being out of true. This is often caused by too much strain on the pulley. When the shaft is out of true, it is best to remove the revolving part of the machine, place it in a lathe, straighten the shaft, and smooth and polish the bearing portion of the shaft. It sometimes happens that the hot bearing is due to heat conducted through the iron from the windings. This can usually be noted by comparing the temperature of the bearings and the windings with

the hand. When the trouble is due to the windings, the load on the motor, or generator, should be reduced.

Hot Windings. This defect is usually first noticed when the insulation on the winding begins to smoke. The machine should be stopped at once and the windings examined. If only a few of the coils are hot, the trouble may be caused by short circuits in that part of the winding, or by one or two grounds. Two grounds in a winding will act the same as short circuit. In case the rotor of the machine is not centered properly and the air gap is less on one side than on the other, there will be a tendency for some of the coils to overheat. If the machine is stopped soon enough, it may not be necessary to replace any coils or only a few of them, instead of rewinding the whole machine.

REPAIRING WINDINGS

Replacing Defective Coils. When the defects in the windings of single-phase motors or small- and medium-sized polyphase induction motors and generators is confined to one or two coils, it is often possible to remove the defective windings and wind a new coil into the slots without disturbing the other coils. The method of doing the work is very similar to the winding of single-phase motors by hand. With repair jobs, it is often necessary to insert one side of the coil in the bottom of the slot, and in these cases the slot wedges must be removed from the slots containing the defective coils. The top coils that are over the defective bottom coils can be raised partly out of the slot so that new insulation can be placed in the slot. The coil can then be wound in the bottom of the slot by estimating the length of the wire needed and pushing the insulated wire through the slot from the end until the desired number of turns are in place. In winding the wire in the slot, care must be taken to arrange the wires in layers and as tight and as close together as possible otherwise it will be very difficult to place the coil that is in the top of the slot in place.

The same kind and size of insulated wire should be used in repair work as was used when the machine was built. The majority of the windings on motors and generators use double cotton-covered copper wire. In repair work, enamel double-cotton covered wire can be used to good advantage because the enamel insulation is very thin

and does not occupy very much space. The reason that it is not used very much on new work is due to the fact that it is difficult to remove the enamel before soldering the connections. When the wire is of small size, No. 28 or smaller, double-silk covered, or enamel, and a single covering of silk is used.

Recording Data. It is desirable that all the necessary data be taken from the old winding before it is removed as it will prevent mistakes and unnecessary time in placing the new winding in position. If the winding is a new one to the winder, it is best to make a diagram of the connections of the pole-phase groups and the connections of the phases. The standard connection diagrams for a certain number of poles and the method of connecting the pole-phase groups in series or in parallel is given in the next section. There are a number of different methods of connecting the pole-phase groups in order to obtain the same number of poles with the series and parallel arrangement of the groups.

When the winder has connected a number of motors of the same kind, it is not necessary to draw a diagram; only the necessary data should be taken and recorded, which is as follows: number of coils; number of coil groups; number of coils per group; and coil span, slot 1 to ——.

On single-phase machines, the above data should be recorded for both the main and auxiliary or starting windings and, in addition, a sketch should be made showing the connection of these windings. A complete coil should then be removed from the windings for a sample and guide in winding and shaping the new coils. As the winding is being removed, the following data should be taken and recorded: Number of conductors in parallel; number of turns per coil; size of wire; weight of wire; kind of insulation on wire; kind and amount of insulation on coil; kind and amount of insulation in slot, and kind and amount of insulation between phases.

The next step is to wind the new coils with the correct size of wire and number of turns as called for in the data taken from the old winding. The method of winding and shaping the coils is the same as described in the preceding sections on direct-current windings and windings on new machines. The detailed procedure will depend entirely upon the equivalent available for doing the work. When the coils are to be used in a core that has open slots, it is best

TABLE I

Cost of Rewinding Polyphase Induction Motor Stators
or
Phase-Wound Rotors

Horse-Power	1800 R.P.M.	1200 R.P.M.	900 R.P.M.
½	$23	$25	$32
¾	24	28	35
1	28	30	40
1½	30	35	43
2	35	40	45
3	40	45	55
5	48	55	65
7½	55	65	75
10	65	75	85
15	75	85	95
20	80	90	110
25	90	115	125
30	100	125	145
50	140	165	190
75	190	210	240

to dip the coils in insulating varnish and bake them in an oven the required number of times necessary to obtain a smooth surface. With the majority of generators and motors, however, a partial closed slot is used and for these the coils must not be dipped or baked, because it is necessary to bend the wires when placing them in the slots and the insulation on a dipped coil is too brittle to allow this.

When the machine that is to be rewound is of large size or the coils require special size conductors or insulation, it is better to purchase the coils from the manufacturer. The connections of the windings on the armature or stator of a polyphase machine is essentially the same for a generator and an induction or synchronous motor. It is not advisable for the average repair shop to attempt to change the number of turns or size of wire in the coils from that of the original machine. However, the coils and pole-phase groups may be reconnected so that the motor can be operated at a changed phase, voltage, frequency, and speed.

Cost of Repairs. The prices given in Table I will serve as a guide in estimating the cost of rewinding standard makes of two- or three-phase induction motor stators that can be operated on 110-, 220-, 440-, or 550-volt circuits. The cost of rewinding rotors that have slip-rings and others in which the windings are insulated from the

core and each other is the same as for stator windings. The above prices assume that the old winding is on the core and a new winding of the same data is placed on the core. When the voltage of the stator winding is 2300, the cost due to the use of a greater amount of insulation will be about 25 per cent higher than for a 110- to 550-volt motor.

The connection between the end rings and the copper bars in the slot of a squirrel-cage rotor sometimes become loose or make poor contact. These can be brazed or welded together by using an acetylene torch. The cost of doing this work will be about 20 per cent of the prices given in Table I. There are so many different makes and kinds of single-phase motors that it is impossible to give comparative costs for the different sizes of motors. As a general rule the cost of rewinding a single-phase stator is one and one-half to two times that for a polyphase winding.

Reconnecting Windings. It is often necessary to change the connection of the coils and pole-phase groups, number of phases, frequency, and speed from that for which the motor was originally designed in order to enable it to operate at a different voltage. The majority of electrical circuits that furnish power to induction motors are three-phase and have a frequency of 60 cycles. A frequency of 25 cycles is often used in some industrial plants that produce their own power. This frequency is used to a considerable extent in steel rolling mills where it is desirable to operate large machinery at very slow speed. There are some power plants that use a two-phase system having a frequency of 40 cycles per second, although their number is becoming less due to their being changed over to a three-phase system with a frequency of 60 cycles. The great number of changes in the windings are to take care of a change in voltage or speed.

Changes in Voltage. It is often necessary to make changes in the windings so that the motor can be operated on a circuit that has a different voltage than that for which it was connected. There is an increasing tendency of the large power companies to furnish power to a customer at 110, 220, or 440 volts for operating motors. When the changes are for voltages similar to these it can be accomplished by changing the pole-phase groupings from parallel to series or the reverse, as in Fig. 11. As an example, assume that the winding has

four groups in series as in Fig. 5 and is operated on a 440-volt circuit. The connection of the coils can be represented as *a*, Fig. 11. It is seen from the diagram that the voltage from each group of coils is 110 volts. For a 220-volt circuit, the coils would be connected as at *b*, in which there are two groups in series and two series groups in parallel. When it is desired to reconnect it for 110 volts all the coils would be connected in parallel as in *c*, Fig. 11.

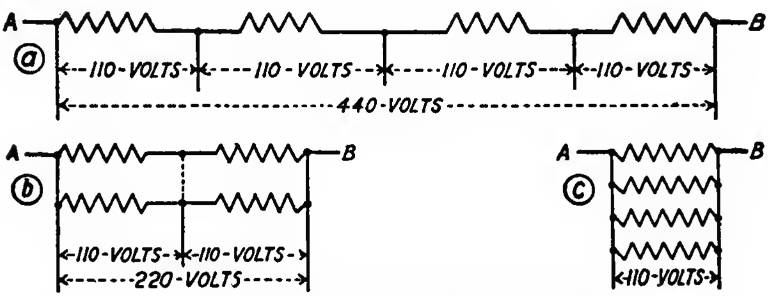


Fig. 11. Typical Series and Parallel Connections

The windings of a three-phase motor can be changed from delta to star or vice versa and thus enable it to be operated on the new

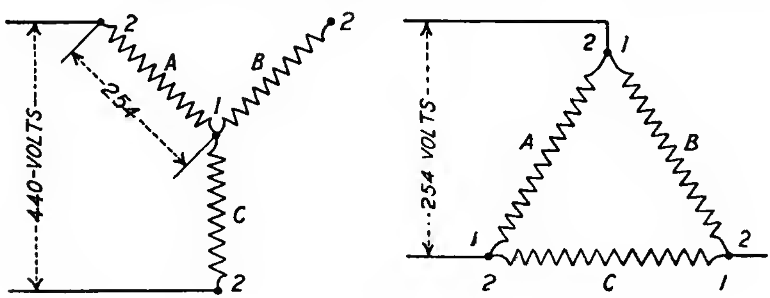


Fig. 12. Star and Delta Connections

voltage. Thus, if the motor has a star-connected winding, as shown in Fig. 12, and is operated on 440 volts, it can be reconnected for a delta connection that will operate on 254 volts. In Fig. 12 the three phases are represented by the lines marked *A*, *B*, and *C*. The point marked 1, which is the common connection of the three phases, is called the neutral point. The three leads that are brought outside the motor are connected to the terminals marked 2. With a star-

TABLE II

Comparison of Motor Voltages with Various Connections

	3-Ph. Series Star	3-Ph. 2-Par. Star	3-Ph. 3-Par. Star	3-Ph. 4-Par. Star	3-Ph. 5-Par. Star	3-Ph. Series Delta	3-Ph. 2-Par. Delta	3-Ph. 3-Par. Delta	3-Ph. 4-Par. Delta	3-Ph. 5-Par. Delta	2-Ph. Series	2-Ph. 2-Par.	2-Ph. 3-Par.	2-Ph. 4-Par.	2-Ph. 5-Par.
3-Ph. Series Star	100	50	33	25	20	58	29	19	15	12	81	41	27	20	16
3-Ph. 2-Par. Star	200	100	67	50	40	116	58	38	29	23	162	81	54	40	32
3-Ph. 3-Par. Star	300	150	100	75	60	174	87	57	44	35	243	122	81	60	48
3-Ph. 4-Par. Star	400	200	133	100	80	232	116	76	58	46	324	163	108	80	64
3-Ph. 5-Par. Star	500	250	165	125	100	290	145	95	73	58	405	203	135	100	80
3-Ph. Series Delta	173	86	58	43	35	100	50	33	25	20	140	70	47	35	28
3-Ph. 2-Par. Delta	346	172	116	86	70	200	100	66	50	40	280	140	94	70	56
3-Ph. 3-Par. Delta	519	258	174	129	105	300	150	100	75	60	420	210	141	105	84
3-Ph. 4-Par. Delta	692	344	232	172	140	400	200	133	100	80	560	280	188	140	112
3-Ph. 5-Par. Delta	865	430	290	215	175	500	250	165	125	100	700	350	235	175	140
2-Ph. Series	125	63	42	31	25	73	37	24	18	15	100	50	33	25	20
2-Ph. 2-Parallel	250	125	84	63	50	146	73	49	37	29	200	100	67	50	40
2-Ph. 3-Parallel	375	188	125	94	75	219	110	73	55	44	300	150	100	75	60
2-Ph. 4-Parallel	500	250	167	125	100	292	146	97	73	58	400	200	133	100	80
2-Ph. 5-Parallel	625	313	208	156	125	365	183	122	91	73	500	250	167	125	100

Note—If a motor connected originally as shown in any horizontal column had a normal voltage of 100 its voltage when reconnected as indicated in any vertical column is shown at the intersection of the two columns.

or Y-connection the voltage on each phase of the motor winding is about 57.7 per cent of the line voltage. In other words, the voltage between the line wires is 1.73 times that of one of the phase windings.

A combination of series-parallel and star-delta methods can be used to good advantage as shown in Table II. It is assumed that the voltage for which the motor was originally connected is 100 volts, while the vertical columns show how the motor was reconnected. The figures at the intersection of the vertical and horizontal columns give the voltage for the reconnection. If it is desired, the numbers can be considered as per cent. It will be seen, that if a 3-phase 4-parallel star-connected motor is reconnected so that it will be a 4-parallel delta-connected motor, it will operate on a voltage that is 58 per cent of its former line voltage. The new voltage can be very easily determined by taking the present connection and following the horizontal line until the vertical line is intersected that has the proper voltage to which it is desired to change the motor. If the voltage given does not vary more than 10 per cent above or below the actual line voltage, the operation of the motor will usually be satisfactory.

Changes in Frequency. The most common change in frequency is from 25 cycles to 60 cycles or from 60 to 25 cycles. There is also some changing from 60 cycles to 50 and a few changes from 60 to 40, or the reverse. The most important and easiest noted result of changing the frequency is a change in the speed of the motor. The speed of any alternating motor is expressed in the following formula:

$$\text{Speed (r. p. m.)} = \frac{\text{number of cycles} \times 120}{\text{number of poles}}$$

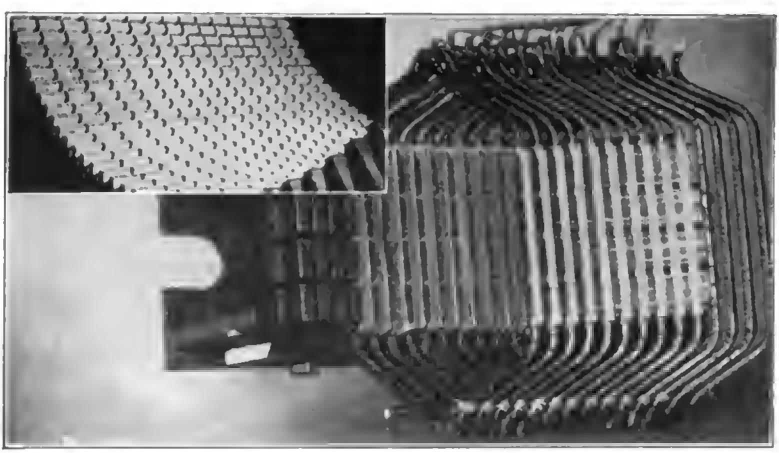
Thus, when a 25-cycle motor is operated on a 60-cycle circuit, its speed will be $\frac{60}{25}$ times the speed that it was on 25 cycles. It is usually desirable to keep the speed on the new frequency about the same as the old speed so it will be necessary to change the number of poles in the winding. It is very difficult and frequently impossible to have the same speed at the new frequency. When the frequency is changed from 25 to 60 cycles, the number of poles is usually doubled.

A change in frequency also affects the operating voltage in the same direct ratio. Thus, when the frequency is doubled, the new

voltage must be doubled in order to keep the magnetic and electrical circuits normal. Also, if the frequency is lowered, the voltage will have to be lowered a like amount.

Changes in Phase. It is sometimes necessary and desirable to change a motor from 2-phase to 3-phase, or vice versa. In changing, it is usually necessary to reconnect a different number of coils in each pole-phase group. The calculations necessary to determine the number of coils in each pole-phase group should be done by an engineer who is familiar with such calculations. It is not advisable for the electrician to attempt this until he has made a thorough study of the subject. The winding of a single-phase motor is so different from a two- or three-phase motor that it is not advisable to consider such a change.

Changes in Speed. A change in speed is made by making a change in the number of poles in the winding. If it is desired to double the speed, the number of poles will be made one-half what it was for the original speed. When the number of poles is changed on a winding, it is usually necessary to make a change in the voltage in the opposite direction in order to keep the magnetic and electrical conditions the same. If the number of poles is doubled, the motor voltage often has to be made one-half what it was formerly.



SECTIONAL VIEW OF A PARTLY WOUND TURBO-GENERATOR STATOR CORE; INSET SHOWS CLOSE-UP VIEW OF TEETH AND SLOTS
Courtesy of Carnegie-Illinois Steel Corp., Pittsburgh, Pa.

CONNECTION DIAGRAMS FOR INDUCTION MOTORS

Standard Diagrams. It is impossible to show developed winding diagrams of induction motor connections in the same manner as for direct-current machines, because with the number of poles, phases, slots, and coils per slot the number of diagrams would be several hundred. However, with polyphase induction motors the method of connecting the coils together into groups is the same, and only the method of connecting the groups varies. The method of determining the number of coils in each pole-phase group is described in the section on "Winding Alternating-Current Motors and Generators." This makes it possible to develop standard diagrams that will apply to motors having different coil pitch, number of slots, and number of coils, because the only factors affecting the diagram are the number of phases, number of poles, number of pole-phase groups that are connected in series or in parallel in each phase winding, and on three-phase windings whether the phases are connected in star (Y) or in delta.

The number of diagrams needed for a three-phase motor is twice that for a two-phase motor because the phase windings may be connected either in star or delta, while in the two-phase machine or motor the phase windings are not connected together. It sometimes happens that a two-phase motor is operated on a two-phase, three-wire system and in these cases one lead of each phase is connected to the common line lead for both phases. It is always best to bring the four leads out of a two-phase motor even when it is known that the motor is to be operated on a three-wire system, because the motor may sometime be used on a two-phase, four-wire system and connections can be made without disturbing the windings.

Pole-Phase Groups. The pole-phase groups of each phase of a winding can all be connected in series, in parallel, or in a series-parallel combination. The different combinations of coil groupings for motors having from 2 to 24 poles are given in Table I. The

rated or synchronous speed in revolutions per minute (r.p.m.) is given in this table for 25-, 40-, and 60-cycle motors. Those in heavy type are the standard speeds for motors of 200 horsepower or less, as recommended by the Electric Power Club—an organization including leading manufacturers of electrical machinery. The speed of the motor when operating at full load is sometimes stamped on the nameplate instead of the no-load or synchronous speed. This speed will be less than that given in the table for a motor with that particular number of poles.

It will be seen by referring to Table I that with a 6-pole motor there are four methods of connecting the pole-phase groups of coils. The six pole-phase groups can be connected all in series, or three pole-phase groups can be connected in series and these two series groups connected in parallel with each other, or two pole-phase groups of coils can be connected in series and these three series groups connected in parallel with each other, or all six pole-phase groups can be connected in parallel with each other.

Explanation of Diagrams. In the standard connection diagrams each arc or segment of the circle indicates a pole-phase group of coils. In the diagrams in this section, the A-phase groups of coils are represented by heavy lines, the B-phase groups by light lines, and the C-phase groups by heavy dotted lines. In three-phase, star-connected (Y) windings the neutral wire or lead connecting the ends of the phase windings together is indicated by a medium dot and dash line. A simple diagram in the center shows quickly how the pole-phase groups are connected. The numbers on these coils refer to the pole-phase groups represented by the segments of the circle. The arrows inside the segments of the circle indicate the direction of flow of the current, assuming that it always enters at the external lead and flows to the neutral or to the other phase lead. The arrows are of assistance in checking the connections, because for any pole-phase group of any phase they should be pointing in the opposite direction from the preceding group of that phase. The reason for this is that the magnetic polarity produced by the pole-phase groups of coils is north, south, north, etc., on around the stator.

Three-Phase 2-Pole Diagrams. The connection diagrams for a three-phase, 2-pole motor are shown in Figs. 1 to 4. In Fig. 1

TABLE I

No. of Poles	No. of Coil Groups		Speed of Motor (r.p.m.)		
	In Series	In Parallel	25-cycle	40-cycle	60-cycle
2	2	0	1500	2400	3600
	0	2			
4	4	0	750	1200	1800
	2	2			
	0	4			
6	6	0	500	800	1200
	3	2			
	2	3			
	0	6			
8	8	0	375	600	900
	4	2			
	2	4			
	0	8			
10	10	0	300	480	720
	5	2			
	2	5			
	0	10			
12	12	0	250	400	600
	6	2			
	4	3			
	3	4			
	2	6			
	0	12			
14	14	0	214	343	514
	7	2			
	2	7			
	0	14			
16	16	0	187	300	450
	8	2			
	4	4			
	2	8			
	0	16			
18	18	0	166	266	400
	9	2			
	6	3			
	3	6			
	2	9			
	0	18			
20	20	0	150	240	360
	10	2			
	5	4			
	4	5			
	2	10			
	0	20			
22	22	0	136	218	327
	11	2			
	2	11			
	0	22			
24	24	0	125	200	300
	12	2			
	8	3			
	6	4			
	4	6			
	3	8			
	2	12			
	0	24			

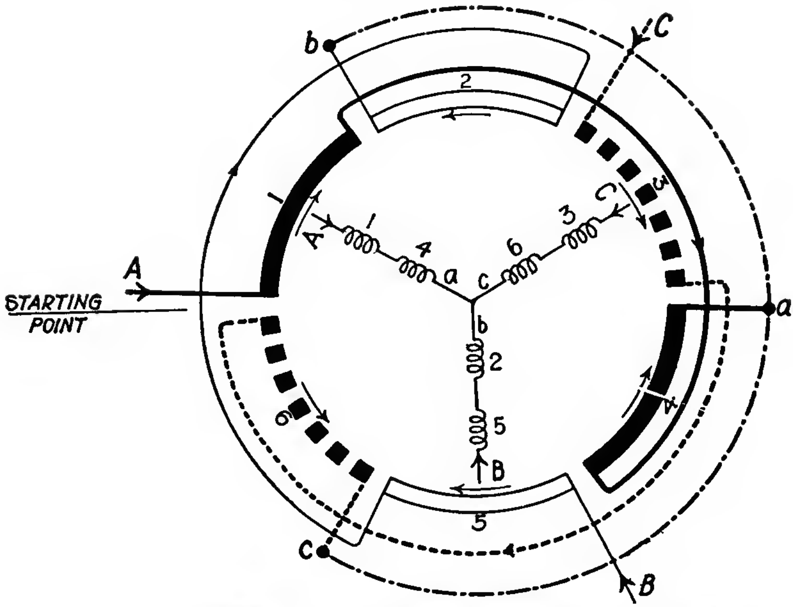


Fig. 1. 2-Pole, Three-Phase, Series-Star Group Connections

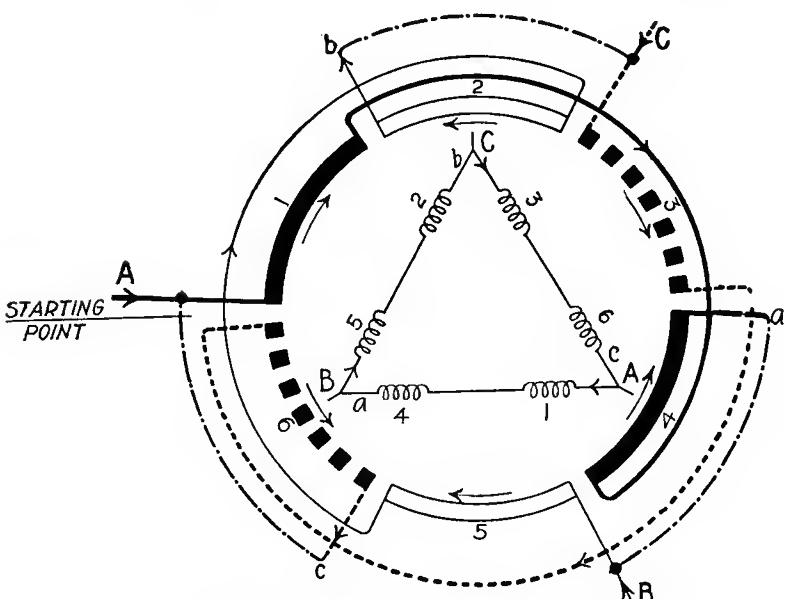


Fig. 2. 2-Pole, Three-Phase, Series-Delta Group Connections

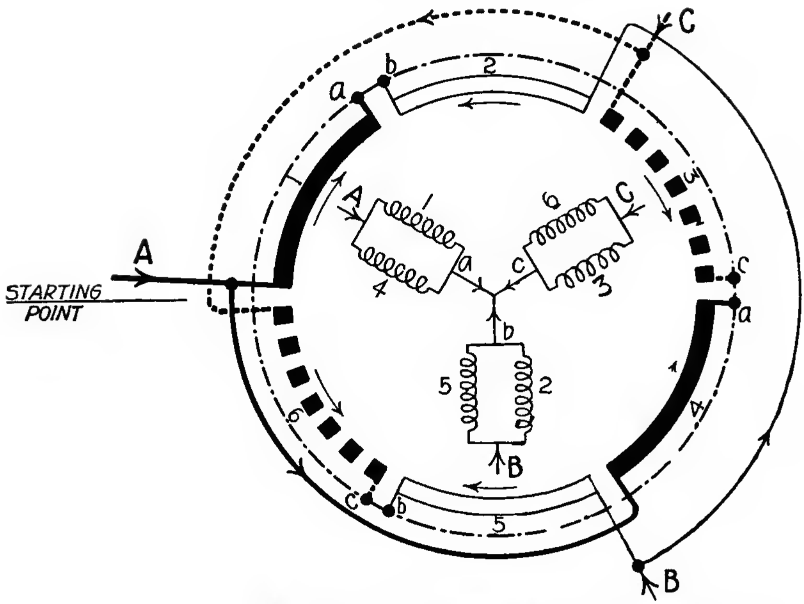


Fig. 3. 2-Pole, Three-Phase, Parallel-Star Group Connections

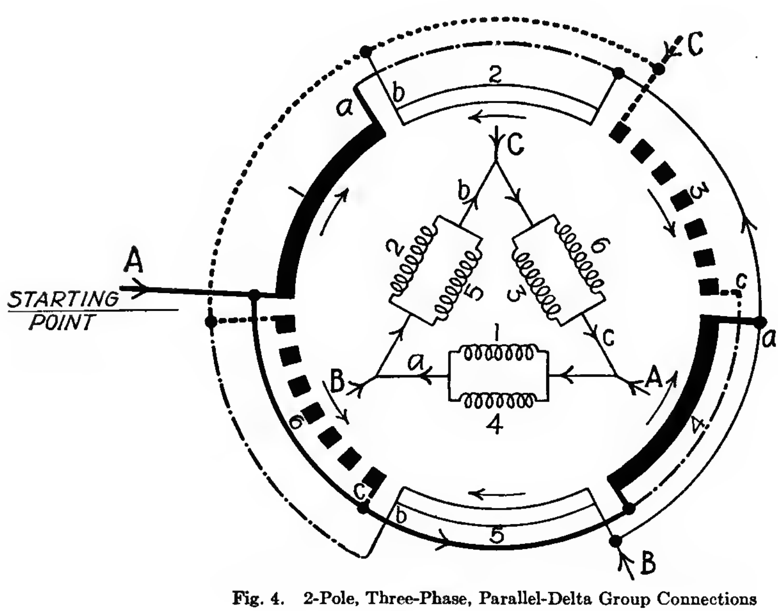


Fig. 4. 2-Pole, Three-Phase, Parallel-Delta Group Connections

the two pole-phase groups of coils of each phase are connected in series and the phases are connected in star, while in Fig. 2 the phases are connected in delta. In the Y connection the *a*, *b*, and *c* ends of the phase windings are connected together, while in the delta connection *a* is connected to *B*, *b* to *C*, and *c* to *A*. The lines marked *A*, *B*, and *C* are the external leads that are brought outside the motor frame.

In Figs. 3 and 4 the two pole-phase groups of each phase are connected in parallel. In Fig. 3 the neutral is a ring formed from insulated or rubber-covered wire of a size approximately one-half that of the line leads. The ring construction makes a neat job. It will be seen that the direction of flow of current in any pole-phase group of coils in the four diagrams is the same, and using a different grouping or connection does not change this relation.

Three-Phase 4-Pole Diagrams. The different connection diagrams for a three-phase 4-pole motor are shown in Figs. 5 to 10. In Fig. 5 the four pole-phase groups of coils are connected in series and the phases are connected in Y or star while in Fig. 6 the phases are connected in delta. The pole-phase groups are connected in the same manner in both of the diagrams and the only difference is in the way the connections are made beyond the end of the phase windings. In Fig. 6, as in other diagrams of delta connections, the leads connecting the end of one phase to the next are represented by dot and dash lines the same as the neutral connections.

In Figs. 7 and 8 the connections are shown when two pole-phase groups are in series and the two series groups connected in parallel. The neutral connection in Fig. 7 can be made a ring as in Fig. 3 and will be mechanically stronger than that shown. In Fig. 8 a ring is used for each phase and the ends of the two pole-phase groups that are in series are connected to these rings. This method is used when the pole-phase coils are connected in parallel as in Figs. 9 and 10. With the Y connection there are four rings and the pole-phase coils are connected between the phase rings and neutral as in Fig. 9. With the delta connection the pole-phase coils are connected between the phase wires as in Fig. 10.

Three-Phase 6-Pole Diagrams. There are four different combinations in which the pole-phase groups of coils can be con-

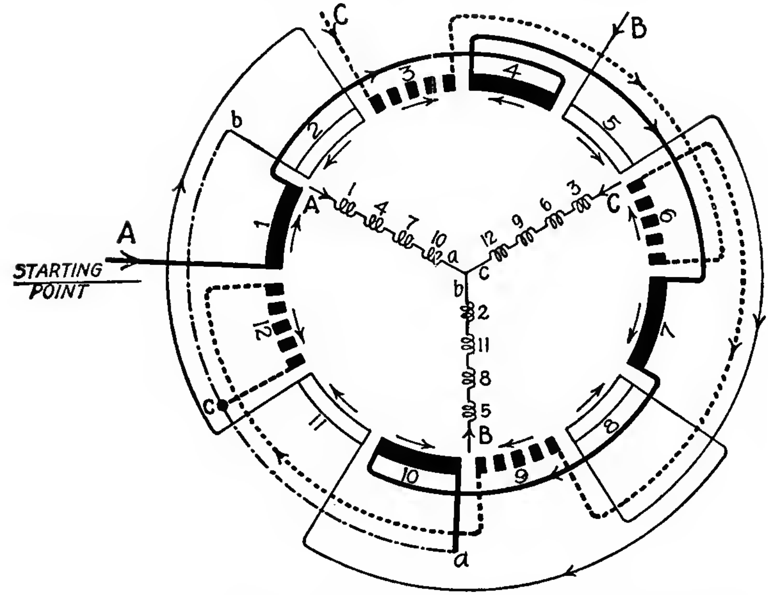


Fig. 5. 4-Pole, Three-Phase, Series-Star Group Connections

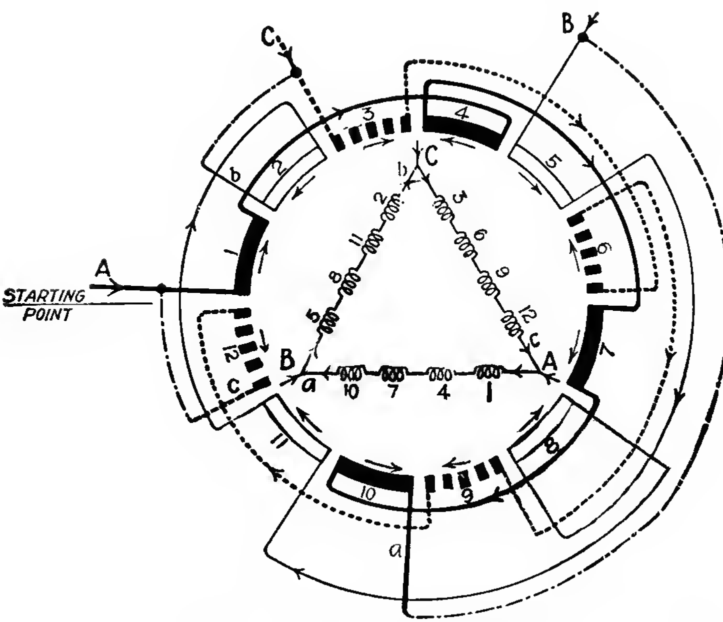


Fig 6 4-Pole, Three-Phase, Series-Delta Group Connections

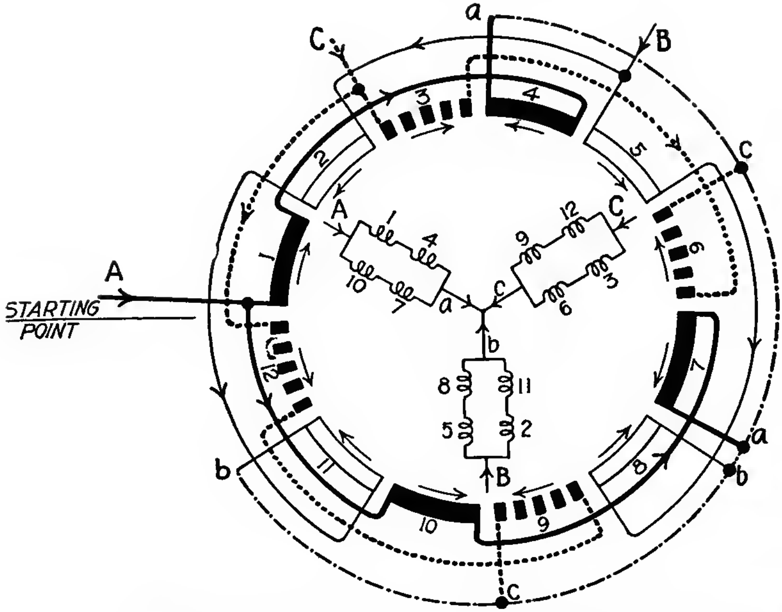


Fig. 7. 4-Pole, Three-Phase, Two-Series, Two-Parallel Star Group Connections

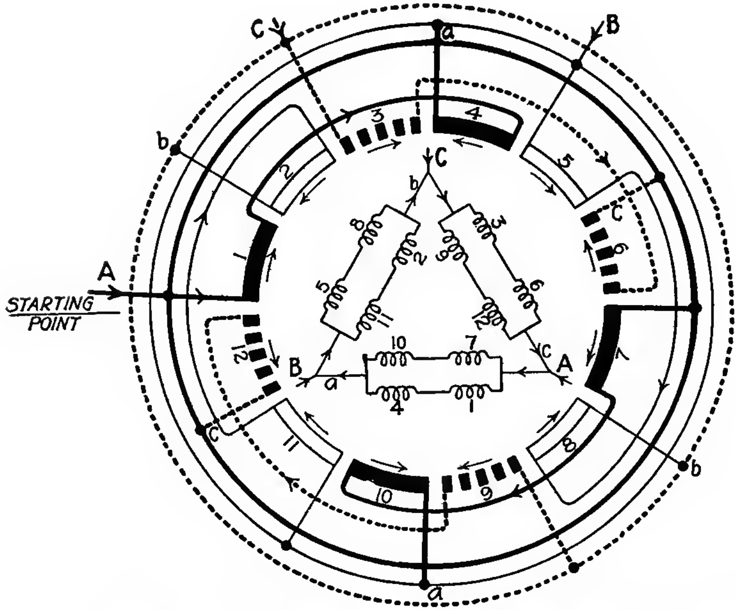


Fig. 8. 4-Pole, Three-Phase, Two-Series, Two-Parallel Delta Group Connections

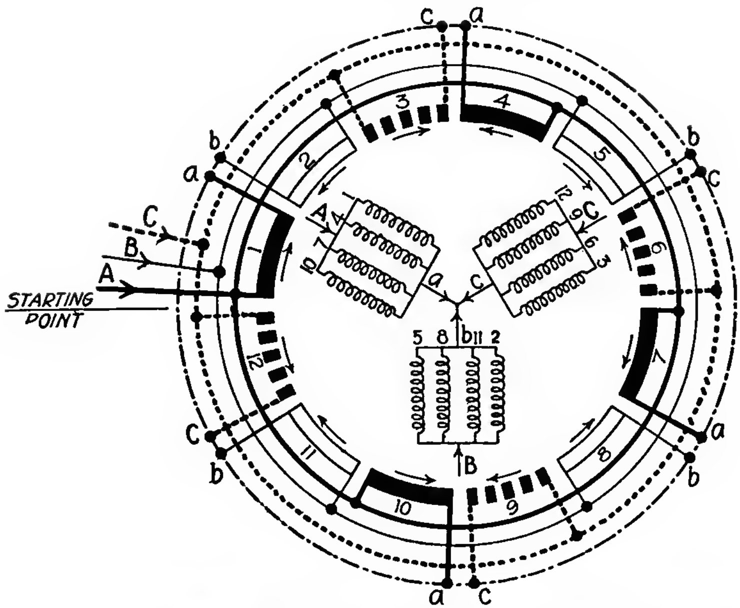


Fig. 9. 4-Pole, Three-Phase, Four-Parallel Star Group Connections

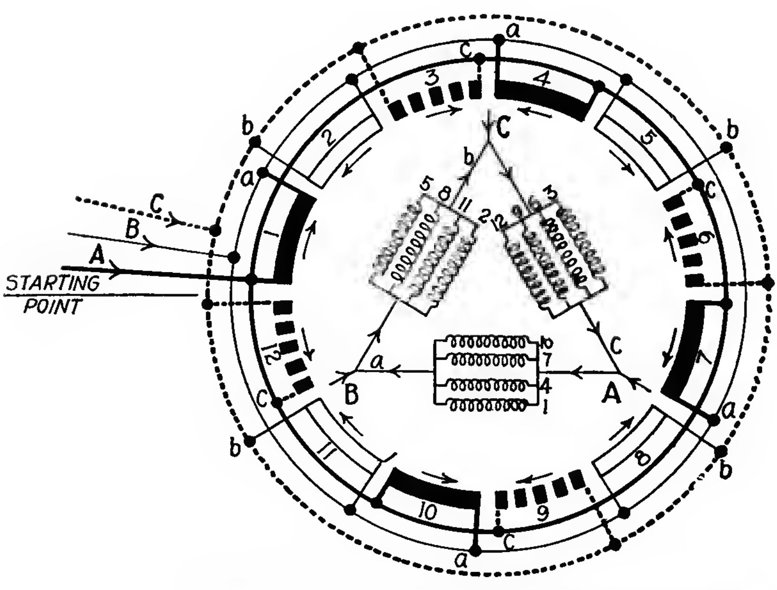


Fig. 10. 4-Pole, Three-Phase, Four-Parallel Delta Group Connections

nected for a 6-pole winding, as will be seen by referring to Table I, and each combination can be connected either in Y or delta, thus calling for eight diagrams of connections. These diagrams are shown in Figs. 11 to 18. In Figs. 11 and 12 all the pole-phase groups of coils are connected in series, while in Figs. 13 and 14 there are three pole-phase groups in series and two of the series groups are connected in parallel with each other. In these two diagrams the three pole-phase groups on one side of the stator are in series and the three on the other side are in series. This method of connection brings the ending or neutral ends of the series pole-phase groups on the opposite side from the starting point or where the external leads are connected to the windings. The external leads are connected to the terminals *A*, *B*, and *C*.

In Figs. 15 and 16 there are two pole-phase groups in series and three of these series groups are connected in parallel. In Fig. 15, which is a Y-connected winding, a neutral ring is used; in Fig. 16 three rings are used, and these rings are attached to the external motor leads. When the pole-phase groups are in parallel, as in Figs. 17 and 18, the ring method of connection is used and the pole-phase groups are connected between the phase ring and neutral in Y connection or between two phase rings in the delta connection.

Two-Phase 8-Pole Diagrams. The connection diagrams for two-phase, 8-pole windings are shown in Figs. 19 to 22. There are four external leads brought outside the motor from the windings and they are usually marked *T1*, *T2*, *T3*, and *T4*. The *T1* and *T3* leads are for one phase and would be connected to *A* and *A'* leads in these diagrams, and the *T2* and *T4* leads would be connected to *B* and *B'* leads. In these diagrams *A* and *B* markings will be used so that they will correspond to the three-phase diagrams. The connecting of the winding for a two-phase motor is simpler than for a three-phase motor, because there are only two phase-groups of coils and when connecting one phase every other group belongs to that phase. One important fact must be remembered: with two-phase windings (and this also applies to single- and three-phase windings) each pole-phase group of that phase must be connected so that current will flow in it in the reverse direction from the pole-phase group of that phase on either side of it. This is necessary in order that magnetism produced by the current in that

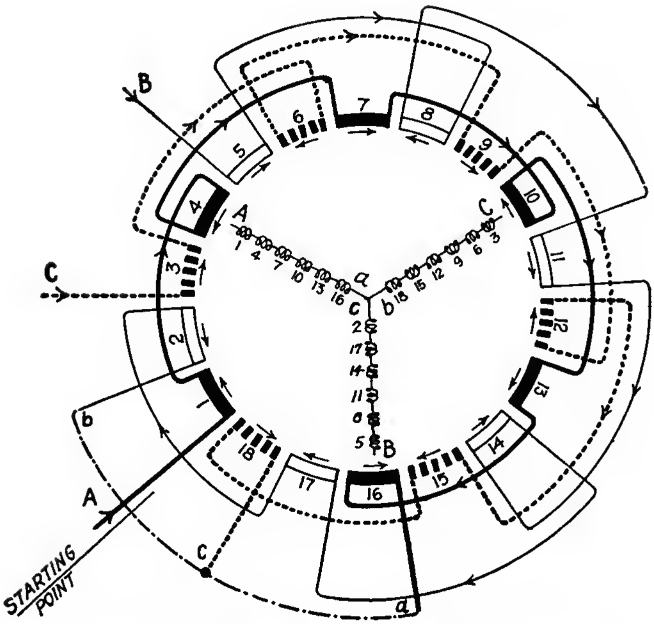


Fig. 11. 6-Pole, Three-Phase, Series-Star Group Connections

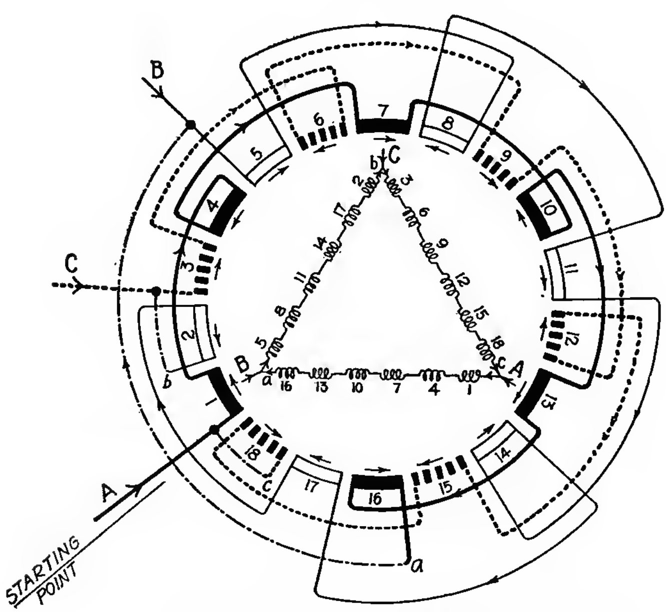


Fig. 12. 6-Pole, Three-Phase, Series-Delta Group Connections

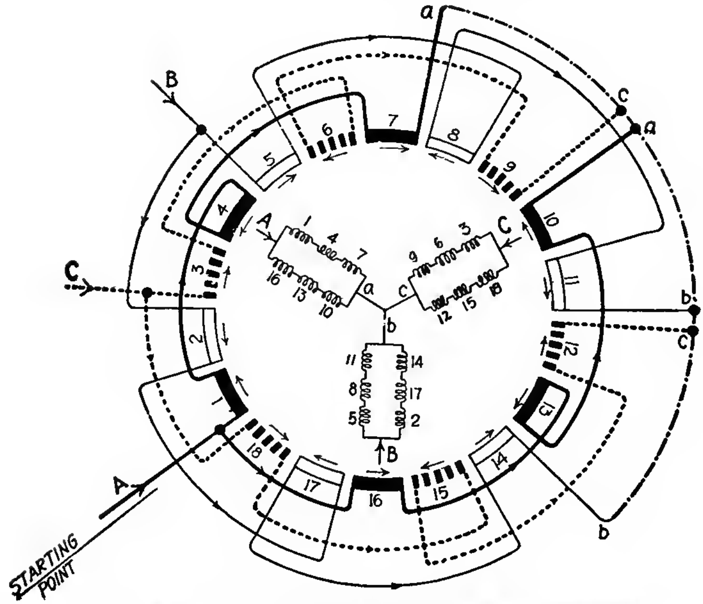


Fig. 13. 6-Pole, Three-Phase, Three-Series, Two-Parallel Star Group Connections

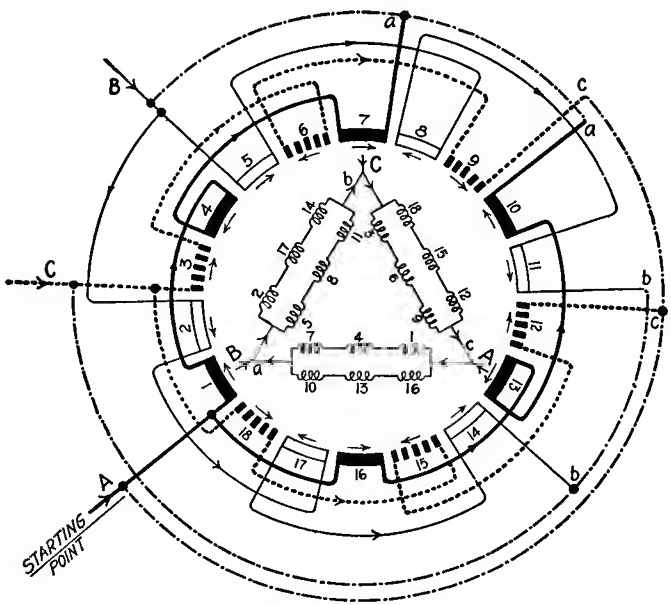


Fig. 14. 6-Pole, Three-Phase, Three-Series, Two-Parallel Delta Group Connections

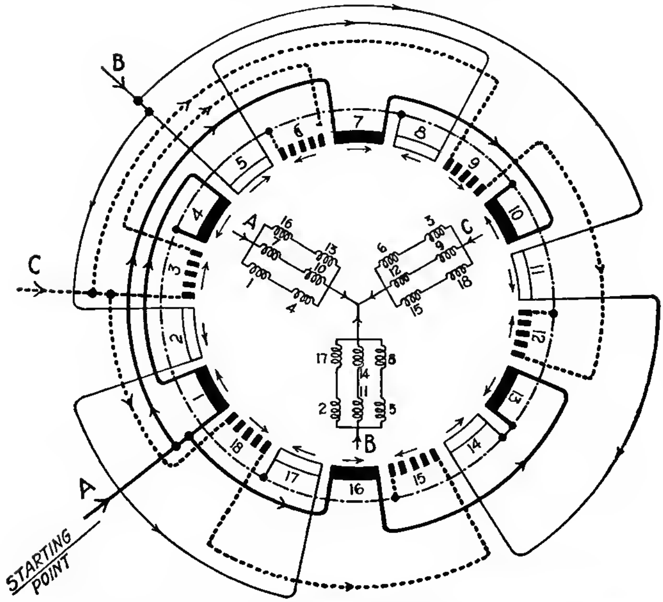


Fig. 15. 6-Pole, Three-Phase, Two-Series, Three-Parallel Star Group Connections

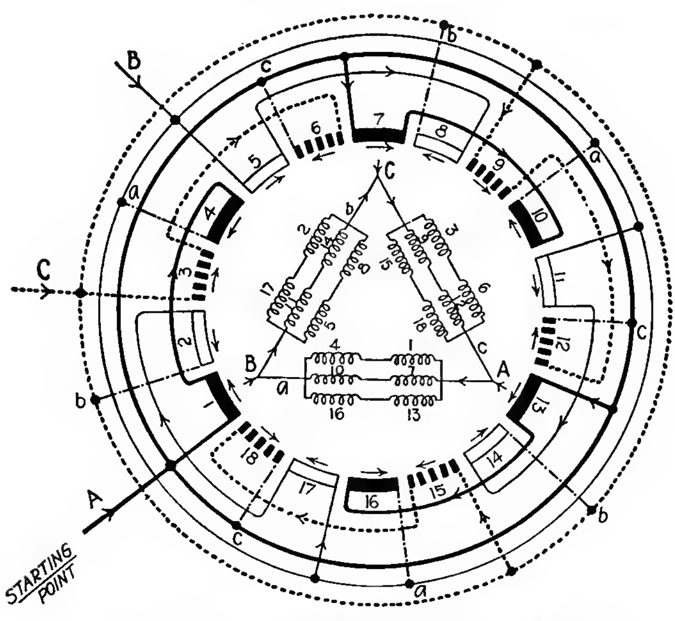


Fig. 16. 6-Pole, Three-Phase, Two-Series, Three-Parallel Delta Group Connections

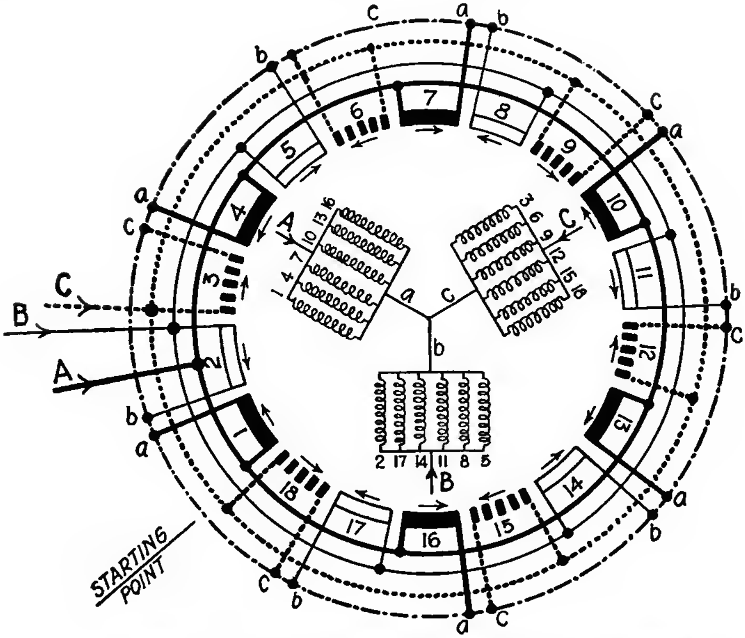


Fig. 17. 6-Pole, Three-Phase, Six-Parallel Star Group Connections

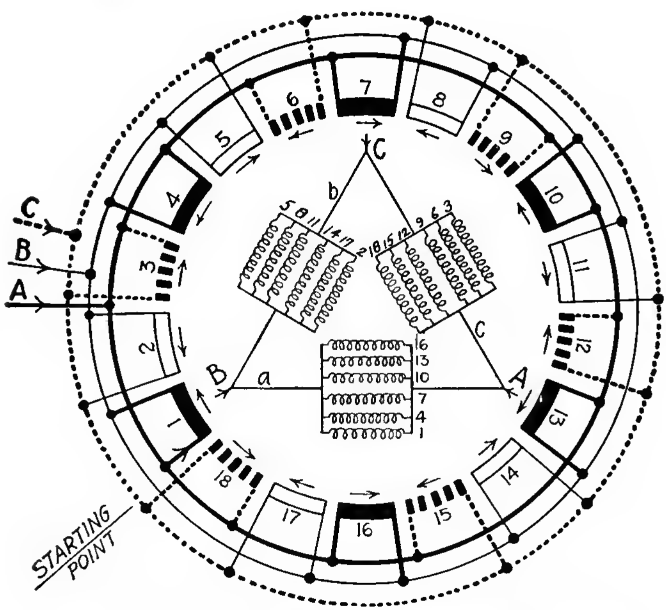


Fig. 18. 6-Pole, Three-Phase, Six-Parallel Delta Group Connections

phase-group of coils will be of opposite polarity to that produced by the pole-phase groups of that phase on either side of it.

In a two-phase winding the direction of the flow of current and magnetic polarity produced by current flowing through the pole-phase groups of coils is different from a three-phase winding, Fig. 19. In this figure the current is entering the winding at the *A* and *B* leads and passing out at the *A′* and *B′* leads. As indicated by the arrows, the current will flow in the same direction in two adjacent pole-phase groups, then in the opposite direction for two pole-phase groups, then in the first direction for two more groups, and so on, all around the stator winding. When the polarity of the pole-phase groups is checked by passing direct current into the *A* and *B* leads and out of the *A′* and *B′* leads and testing the polarity of the inside of the stator core with a compass, it will be found that there are two north poles, two south poles, two north poles, etc., together. This is just the opposite of the polarity indications obtained when testing a three-phase winding. If this fact is not remembered there will be confusion when a two-phase winding is being tested, especially when the majority of the work is with three-phase windings.

In Fig. 19 all the pole-phase groups of each phase are connected in series. In the center of the drawing the simple diagram or representation of a two-phase winding is shown. There is no connection at the center between the two phases. In a two-phase winding the two phases are 90 electrical degrees apart, so in a simple diagram the windings are represented as being at right angles to each other. In Fig. 20 four pole-phase groups are in series and two of these groups are in parallel in each phase. In connecting the pole-phase groups, those in the upper half of the winding beginning at the *A* lead are connected and then those in the lower half, beginning at *A*, are connected in like manner. This brings the ending end of the windings or connections on the opposite side from the beginning. The external leads that are brought outside of the motor frame can be connected to the *A′* and *B′* leads at this point as easily as at any other point. The other two external leads are connected to *A* and *B*.

A two-series, four-parallel connection is shown in Fig. 21. With this winding the best method of connecting the pole-phase

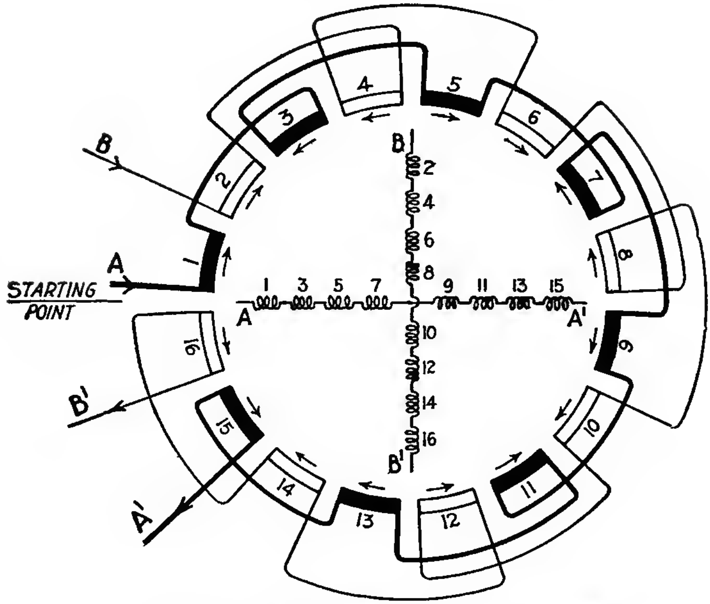


Fig. 19. 8-Pole, Two-Phase, Series Group Connections

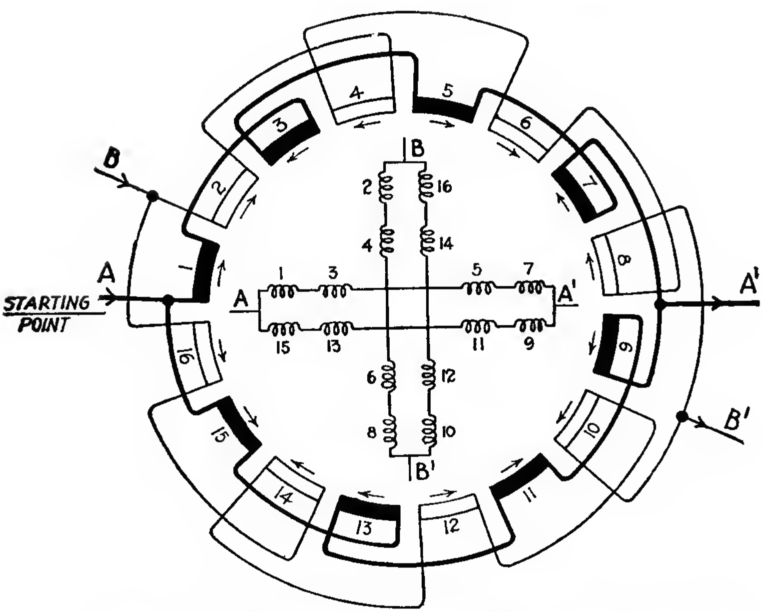


Fig. 20. 8-Pole, Two-Phase, Four-Series, Two-Parallel Group Connections

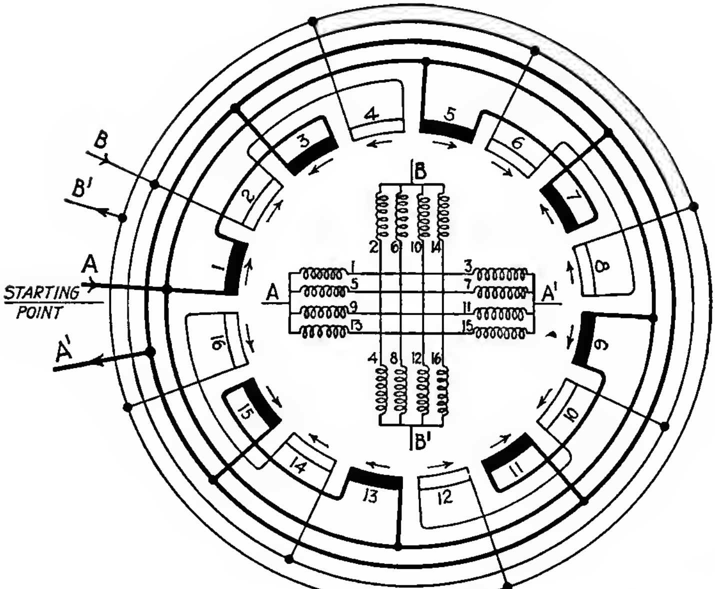


Fig. 21. 8-Pole, Two-Phase, Two-Series, Four-Parallel Group Connections

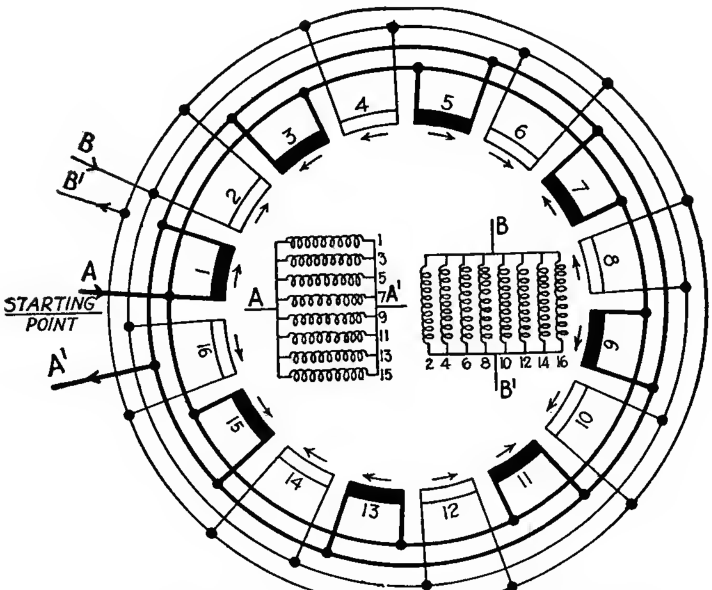


Fig. 22. 8-Pole, Two-Phase, Eight-Parallel Group Connections

groups is to use the ring method, which is similar to that used with parallel connections on three-phase motors. This same method is used on a two-phase winding when all the coils are in parallel, Fig. 22. It is necessary to alter the simple diagram in the center due to the large number of coils in parallel.

Three-Phase 8-Pole Diagrams. The connection diagrams for three-phase 8-pole windings are shown in Figs. 23 to 30. In Fig. 23 all the pole-phase groups are connected in series and the phases in Y connection, while in Fig. 24 the phases are connected in delta. The connections when four pole-phase groups are in series and the two series groups in parallel is given in Figs. 25 and 26. The opposite method of connecting the pole-phase groups is shown in Figs. 27 and 28. Here there are two pole-phase groups in series and four of these series groups in parallel. Just as in Figs. 29 and 30, where all the pole-phase groups are connected in parallel, these phase rings are run around the top of the winding and the different pole-phase groups are connected to these rings.

Starting Connections. There are several methods used in starting a polyphase, squirrel-cage induction motor. When the size of the motor is five horsepower or less, it is often started by connecting the stator windings directly to the line. On motors of larger size, and sometimes on smaller ones, it is necessary to keep the starting current as low as possible in order not to cause dimming of the lights due to a large drop in voltage. In these cases the motors are started by supplying reduced voltage to the windings during the starting period and until the motor has attained nearly full-load speed and then connecting it directly to the line. The reduced voltage can be obtained either by connecting a resistance in series with two of the leads to the stator windings or by using a small autotransformer which is mounted in a metal case with the starting and running switches which connect it to the line and to the stator windings. When the motor attains full speed, the resistance or autotransformer is disconnected from the circuit and the stator windings are connected directly to the line. This arrangement of apparatus is usually called a compensator or autotransformer. The autotransformers are usually provided with a number of taps on the windings so that the starting voltage can be varied between 50 to 80 per cent of the line voltage.

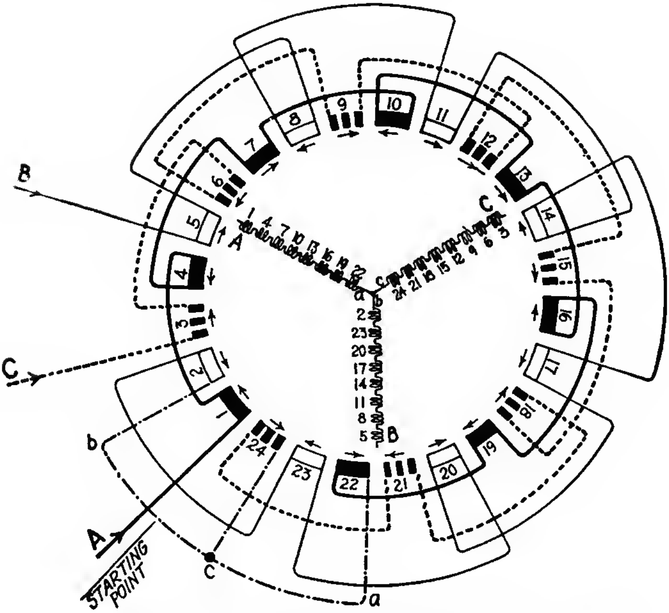


Fig. 23. 8-Pole, Three-Phase, Series-Star Group Connections

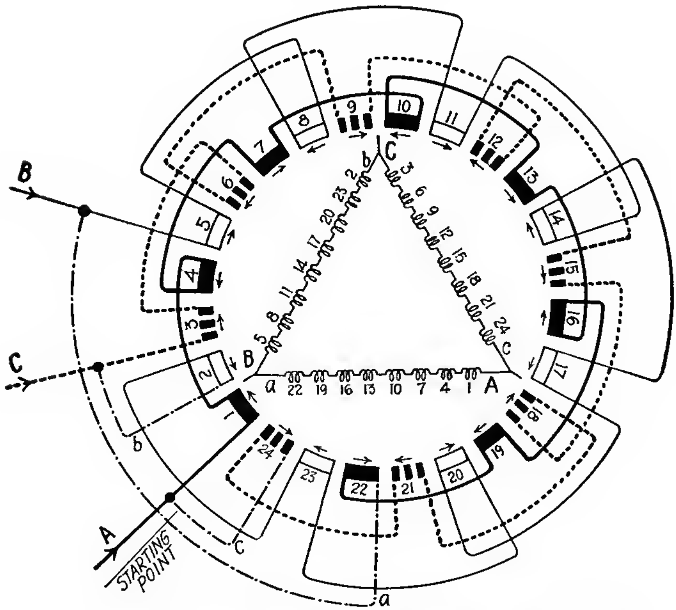


Fig. 24. 8-Pole, Three-Phase, Series-Delta Group Connections

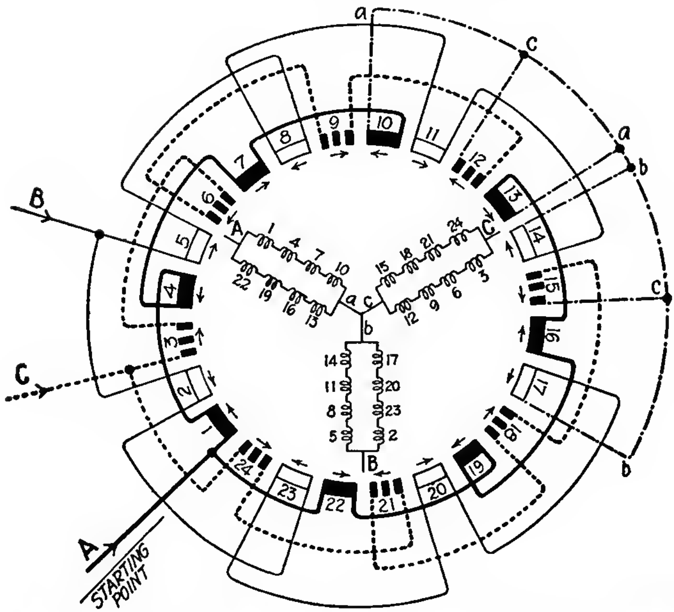


Fig. 25. 8-Pole, Three-Phase, Four-Series, Two-Parallel Star Group Connections

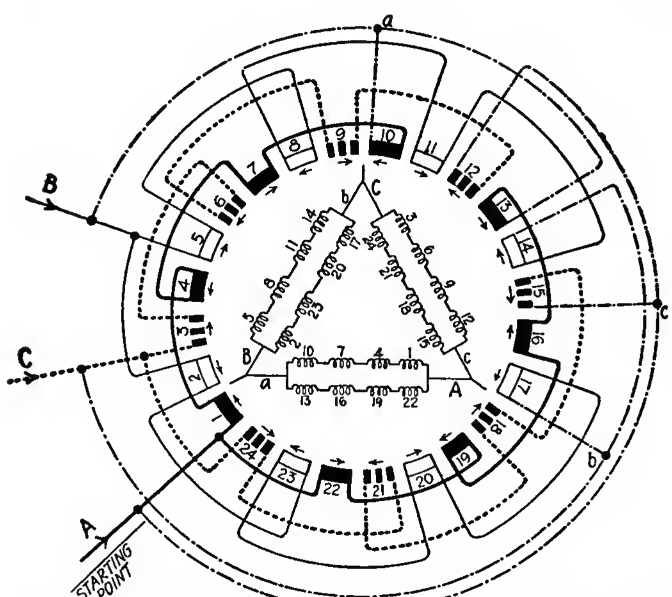


Fig. 26. 8-Pole, Three-Phase, Four-Series. Two-Parallel Delta Group Connections

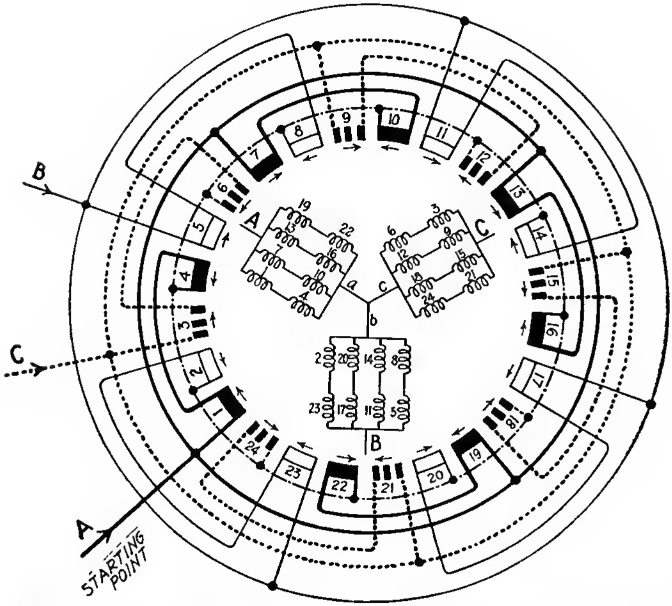


Fig. 27. 8-Pole, Three-Phase, Two-Series, Four-Parallel Star Group Connections

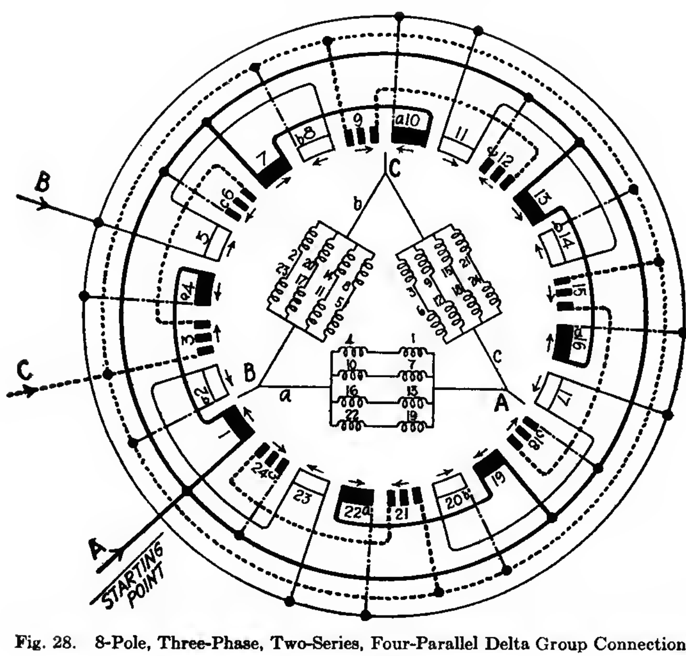


Fig. 28. 8-Pole, Three-Phase, Two-Series, Four-Parallel Delta Group Connections

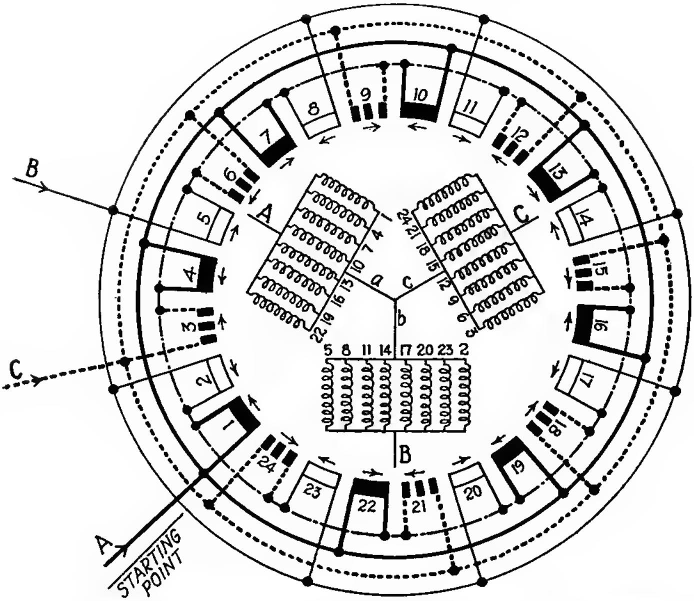


Fig. 29. 8-Pole, Three-Phase, Eight-Parallel Star Group Connections

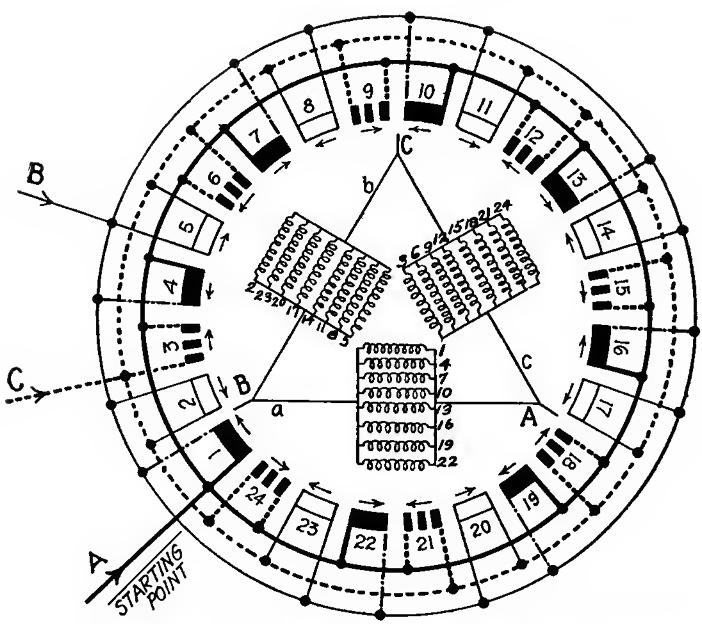
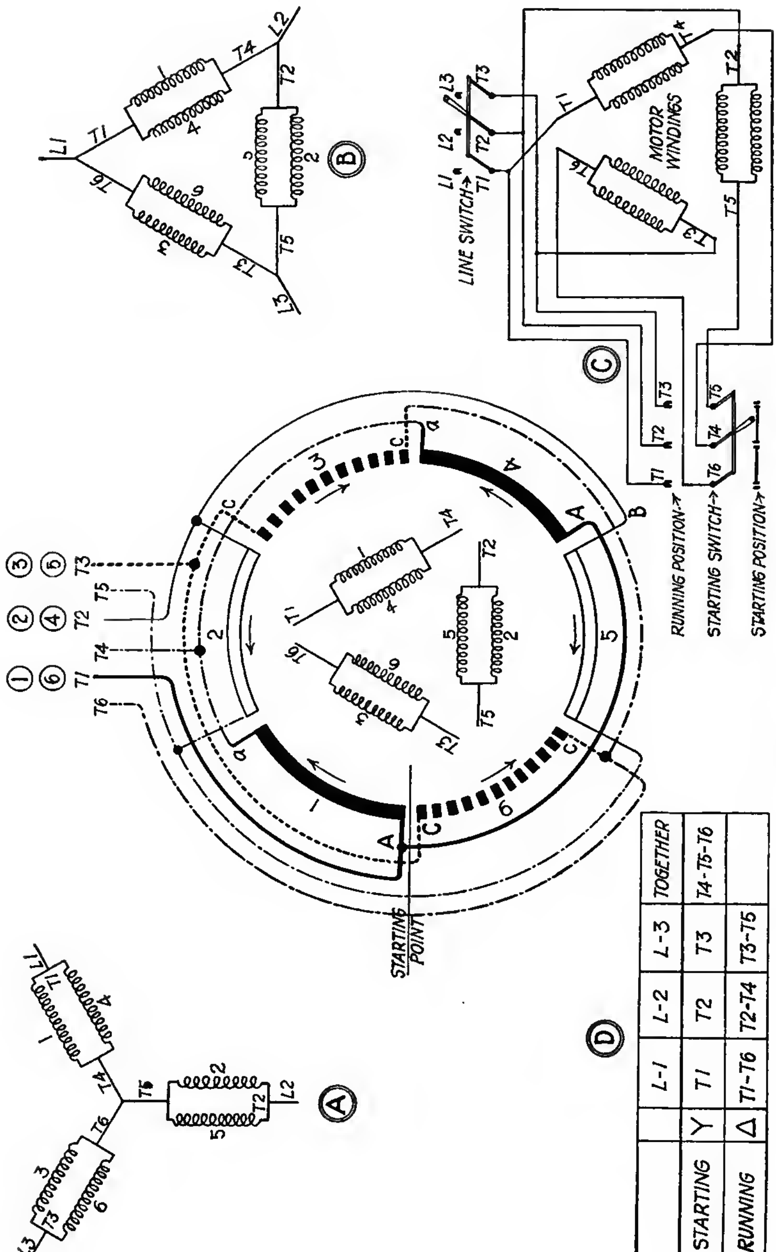


Fig. 30. 8-Pole, Three-Phase, Eight-Parallel Delta Group Connections

Another method is to connect the windings so that the voltage on each pole-phase group of coils will be less than normal during the starting period. This is done by connecting the phases of a three-phase motor in star or Y when starting and in delta when running, or by connecting the pole-phase groups of a two- or three-phase motor in series during starting and then to connect them in parallel when the motor is running at normal speed. The first arrangement is usually called the star-delta method and the second one the series-parallel method.

Star-Delta Starting. The voltage between the ends of each coil of a motor when the phases are connected star or Y is 58 per cent of that when the phases are connected delta. In order that the windings can be changed quickly it is necessary to bring the six leads out from the end of the phases so that they can be connected to switches. The method of connecting the winding and bringing out the leads for a two-pole parallel winding is shown in Fig. 31. It is recommended by the Electric Power Club that when connected to a terminal board or passed through a clamp or insulated block fastened to the frame of the motor the leads be arranged in the order shown by thc circles above them. When such an arrangement is not used, the leads should be tagged *T1*, *T2*, *T3*, *T4*, *T5*, and *T6*. The leads marked *T1*, *T2*, and *T3* are the beginning ends of the phases and *T4*, *T5*, and *T6* are the corresponding ends of the phases. When the windings are connected in Y or star for starting, leads *T4*, *T5*, and *T6* are connected together as shown in *A* Fig. 31 and indicated in *D* Fig. 31. The *T1*, *T2*, and *T3* leads are connected to the line leads which are usually marked or called *L1*, *L2*, and *L3*.

As soon as the motor has attained about full speed, the starting switch *C*, Fig. 31, is thrown from the starting position to the running position which connects the windings of the motor in delta as in *B*, Fig. 31. In this connection *T1* and *T6* are connected to line lead *L1*; *T2* and *T4* to line lead *L2*; and *T3* and *T5* to line lead *L3*. When knife switches are used in starting the motor by this method, it is necessary to use a triple-pole single-throw switch for the line switch and a triple-pole double-throw switch for the starting switch. These two switches are often modified and immersed in oil. They are arranged so that all the operations can be controlled by one handle. The connecting of the motor to the line



		L-1	L-2	L-3	TOGETHER
STARTING	Y	T1	T2	T3	T4-T5-T6
RUNNING	Δ	T1-T6	T2-T4	T3-T5	

Fig. 31. Star-Delta Starting Connections for a 2-Pole, Three-Phase Motor

and changing of connections from star to delta can also be done with a small drum type of controller.

This method of starting cannot be used on all three-phase induction motors. It can only be used when the connection of the windings for full line voltage are connected in delta.

Series-Parallel Starting. The series-parallel method of starting can be used on any two- or three-phase induction motor whose pole-phase groups of coils are connected so that there is an even number of parallel circuits through each phase of the winding when the motor is running at normal speed. It will be seen by referring to Table I that this method can be applied to one-half to three-fourths of the connections of the pole-phase groups for motors having from two to twenty-four poles. This method consists of connecting the pole-phase groups of coils so that twice as many will be in series when the motor is started as when running, and thus the voltage to each pole-phase group will be half the normal voltage. When the motor has reached full speed, the pole-phase connections are changed quickly from series to the normal parallel connection. The changing of connections to series and then back to parallel is usually done with a drum switch or controller. It is necessary to bring out eight external leads from a two-phase, four-wire motor and nine leads from a three-phase motor.

The connections for a two-pole, three-phase Y-connected stator is shown in Fig. 32. It will be noted that both ends of the pole-phase groups numbered *1*, *3*, and *5* are brought outside the motor while one end of the winding for pole-phase groups *4*, *6*, and *2* are connected permanently in Y or star. With a delta-connected winding instead of connecting the *a*, *b*, and *c* leads of pole-phase groups *4*, *2*, and *6* together, *a* would be connected to the *T2* end of group *3*, *c* to *T3*, and *b* to *T1*. The method of bringing out the leads through the motor frame or terminal board is indicated by the circles directly over the motor leads *T1*, *T2*, etc.

The connection of the windings during starting is shown in schematic diagram *A*, Fig. 32. It will be seen that the leads marked *T7* and *T4*, *T8* and *T5*, *T9* and *T6* are connected to each other. This connects the pole-phase groups in series. The parallel connection, which is the running connection, is shown in *B*, Fig. 32. In this connection *T1* and *T4* are connected to *L1*; *T2* and *T5* to

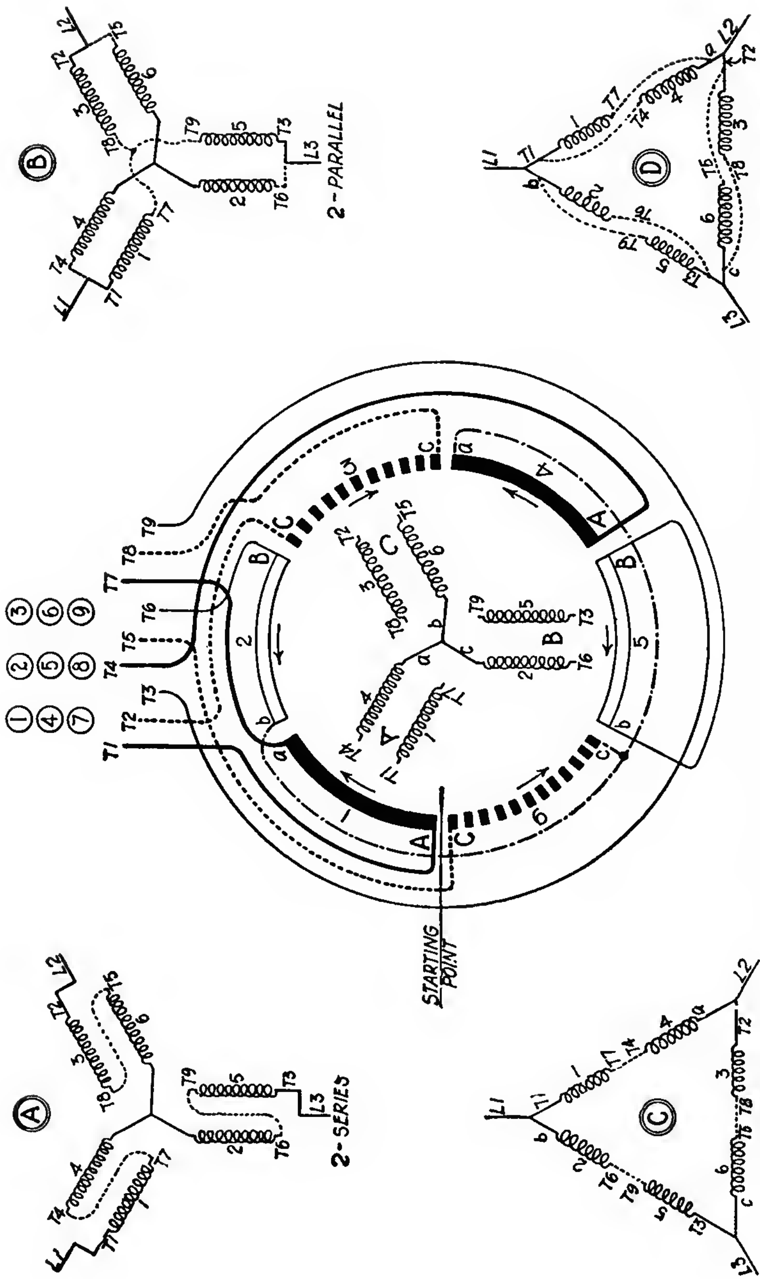
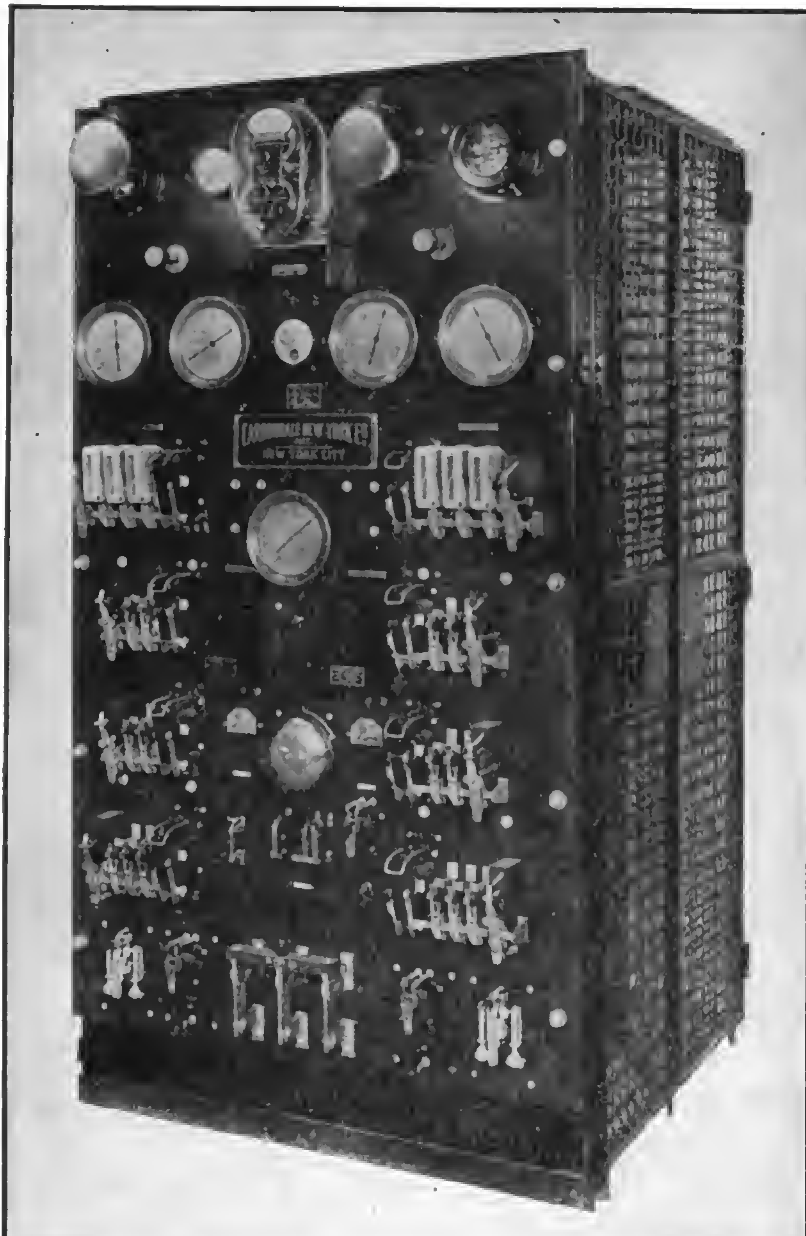


Fig. 32. Series-Parallel Starting Connections for a 2-Pole, Three-Phase Motor

L2; and *T3* and *T6* to *L3;* while *T7*, *T8*, and *T9* are connected together, thus forming the second star or neutral connection in the winding. It will be seen by referring to the arrangement of the leads which are represented by the numbers in the circles that, for starting, the line wires are connected to upper row of leads and the leads in the second row are connected to the leads directly below in the third row. In the running connection the leads in the second row are connected to those directly above and to the line wires, while the leads in the bottom row are all connected together. This connection forms the second neutral.

The arrangement of connections for a delta-connected winding is shown in *C* and *D*, Fig. 32. It will be seen that the external connections for delta starting, *C* Fig. 32, is the same as for Y or star starting. The internal connections are different. In the running connection, which is parallel delta, the following leads are connected together: *T4* and *T9* to *T1;* *T7* and *T5* to *T2;* and *T8* and *T6* to *T3*. The leads *T1*, *T2*, and *T3* are connected to the corresponding line leads *L1*, *L2*, and *L3*.



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Note.—For page numbers, see foot of pages.

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